Digitized by the Internet Archive
in 2019 with funding from
Princeton Theological Seminary Library

https://archive.org/details/certainfactorsin00curt

VOL. XXXII
NO. 4

PSYCHOLOGICAL REVIEW PUBLICATIONS

WHOLE NO. 146
1923

LIBRARY OF
DEC 1 1

Psychological Monographs

EDITED BY

JAMES ROWLAND ANGELL, YALE UNIVERSITY
HOWARD C. WARREN, PRINCETON UNIVERSITY (*Review*)
JOHN B. WATSON, NEW YORK (*J. of Exp. Psychol.*)
SHEPHERD I. FRANZ, GOVT. HOSP. FOR INSANE (*Bulletin*) and
MADISON BENTLEY, UNIVERSITY OF ILLINOIS (*Index*)

STUDIES FROM THE PSYCHOLOGICAL LABORATORY
OF THE UNIVERSITY OF CHICAGO

Certain Factors in the Development of a New Spatial Co-ordination

BY

MARGARET WOOSTER CURTI

PSYCHOLOGICAL REVIEW COMPANY
PRINCETON, N. J.

AGENTS: G. E. STECHERT & CO., LONDON (2 Star Yard, Carey St., W. C.)
PARIS (16 rue de Condé)

ACKNOWLEDGMENTS

To the subjects who so cheerfully and patiently went through with the often protracted series of sittings, I am deeply grateful. Dean James R. Angell I wish to thank for generous interest in this investigation and for inspiring instruction. To Dr. Harvey A. Carr, under whose direction the investigation was carried out, I am grateful for minutely painstaking and searching criticism, and especially for the freedom which he prescribed for me in working out my problem. Those who have done research work under Dr. Carr's direction will understand the statement that it has been one of the greatest privileges in my experience to feel the inspiration of such a scientific attitude as his.

CONTENTS

PAGE

I. INTRODUCTION—STATEMENT OF PROBLEM 1

II. APPARATUS AND METHOD 4

III. DESCRIPTION OF EXPERIMENTAL SERIES AND RESULTS 12

STANDARD SERIES 13

1. Effect of Knowledge of Experimental Conditions
   a. Experiments with knowledge
   b. Experiments without knowledge
2. Effect of Position of Body, Head, and Eyes
   a. Experiments with undistorted vision
   b. Experiments with distorted vision

VISUAL LOCALIZATION OF SOUNDING OBJECTS 47

1. First Group, Using Electric Buzzer
2. Second Group, Using Electric Bell
   a. With vibration visible
   b. With vibration invisible

LOCALIZATION WITH TOUCH 58

1. Passive, as Result of Chance Success
2. Active, as Check at Each Localization

LOCALIZATION WITH VISUAL PERCEPTION OF DISTORTION 63

LOCALIZATION WITH TACTUAL-KINAESTHETIC CLUES FROM LEFT ARM 67

IV. RETENTION OF THE NEW CO-ORDINATION .. 73

V. SPECIFICITY OF READJUSTMENT 75

VI. RELATION OF READJUSTMENT TO DEFINITE LOCALIZING ACTIVITY 89

VII. SUMMARY AND CONCLUSIONS 91

I

INTRODUCTION

The purpose of this investigation was to determine experimentally the relative influence of various sensory modes of reaction, as sight, touch, and hearing, in the building up of a new space habit. This particular habit was developed by the subjects in the process of learning to localize correctly objects seen through prismatic glasses which distorted the visual field.

The perception of space is, to a greater or less extent, the product of individual experience. The adult is able to adjust himself spatially to the outer world only by virtue of the possession of a system of complex habits of reaction. These habits have been slowly and painfully acquired, most of them in infancy. But the process of acquisition as it occurs in infancy is forgotten, and later changes in space reactions come so gradually that the details of the adjustment are not noticed. The adult learns to find a new keyhole in the dark in much the same way that the child learns to pick up his rattle. Hence it is easy to overlook the fact that every move we make depends for its nicety and accuracy upon the unified functioning of an exceedingly intricate reaction system—a system in the building up of which countless simple reactions have played a part.

It would be of great importance for psychological theory to determine the mechanisms underlying the development of this complex system of adjustments. Does the development take place on a purely sensory-motor level, or is it influenced by ideational factors? Is actual movement in space essential, or could a passive subject gain effective perception of a spatial situation? Do all normal individuals develop spatial habits in the same way, or are there individual differences in the matter?

The chief problem discussed in the theoretical literature on the genesis of psychological space so far has concerned the relative importance of various sensory factors. Taste and smell

and the organic and cutaneous modes of activity other than contact, are by common consent held to be of negligible importance in this connection, in spite of the contention of James that all sensations possess original spatial quality. The status of hearing is in dispute. In general, psychologists are inclined to assign it little if any importance as a spatial sense. Contact, however, has been considered to be highly important as a factor in space perception, this attitude being correlative with the popular notion that touching an object is the final test of its real existence. To others vision has seemed the spatial sense preeminent. Vision and touch, it is held by some, are the only senses that "possess real spatial character," and other senses, such as kinaesthesis, become important in space experience only by virtue of their connection with these.

While an enormous quantity of experimental work has been produced bearing on the spatial aspects of the various senses taken in isolation, almost nothing has been done by way of investigating experimentally the relative influence of the various sensory factors as they coöperate in the development of complex types of spatial reaction. Speculation has been supplemented, it is true, by observations on the behavior of young children and of animals; on the reported experiences of congenitally blind persons restored to sight; and on certain cases of alleged abnormalities in the space reactions of adult individuals. But not only has none of the data so adduced as evidence been gathered and presented in a scientifically systematic way, but it does not seem likely that in such fields of observation enough experimental control can ever be introduced to insure validity for the conclusions drawn.

It is possible, however, to demonstrate conclusively, by experimental procedure, certain central facts about the manner in which spatial coördinations *may* develop. If we cannot get at the actual initial processes in the development of the complex world of space for any individual, we can at least investigate experimentally the building up of certain spatial coördinations, by observing what happens when an individual readjusts himself to space relations that have been artificially disturbed. The ex-

perience of people who have gradually become used to a new pair of glasses which alters in any noticeable way the field of vision, offers an illustration of the fact that it is possible through practical experience to readjust one's ordinary coördinations in such a way as to harmonize again disturbed spatial relations.

Strangely enough it was not until comparatively recent years that the idea of investigating the development of spatial organization by producing and then overcoming an artificial disorganization, was conceived and carried out. In 1897 Professor George M. Stratton published his celebrated paper on "Vision without Inversion." The immediate purpose of the experiments reported in that article was to prove that inversion of the retinal image is not a necessary condition of upright vision. They furnished also, however, a striking demonstration of the predominantly empirical character of spatial organization. Incidentally they threw some light on our particular problem of the relative efficacy of various concrete factors in adjustment.

Stratton, it will be recalled, in his main experiment adopted the plan of wearing glasses constructed from lenses which completely reversed the retinal image, and hence directions in the field of vision, so that objects formerly appearing to the right now appeared to the left, and objects formerly in the upper part of the field of vision now looked to be in the lower part. In other words, on first assuming the glasses the entire visual scene appeared to be upside down. Stratton wore these glasses continously for eight days, except during hours for sleeping, when he was carefully blindfolded. He went about his ordinary activities somewhat as usual. He found that not only was he able gradually to make effective practical adjustment to the changed visual situation, but that at the same time the new arrangement came to seem more and more natural to him, until at the end of eight days things no longer appeared to be upside down. A new visual system had even in that short time been more or less completely organized, and harmonized with sense impressions from different fields to such an extent that his space world was again unitary.

This experiment of Stratton's demonstrated first that the inversion of the retinal image is not a necessary condition of normal

vision, the fact which he originally set out to prove. It showed, second, that it is possible in the give and take of ordinary experience to build up an entirely new spatial organization in which various sensory factors come to be associated together in new ways.

In addition to establishing these general facts, Stratton made valuable observations on the role played by various factors contributing to the process of readjustment. It was his main purpose, however, to establish the general fact that harmonious readjustment can occur, rather than to study the specific factors concerned in the process. He made no effort, therefore, during the course of the experiment systematically to investigate the formation of any one coördination, but merely noted down, as the experiment progressed, those observations which seemed to him pertinent. These observations constitute a valuable contribution to the factual study of the more general aspects of space perception, but additional data of a specific and quantitative nature are needed as a basis for more detailed conclusions. In fact it would take the combined results of many individuals to warrant the drawing of such general conclusions.

It is the aim of the present work, then, to contribute something toward the experimental investigation of those factors in the development of space perception which Stratton treated only incidentally. We know now, through his experiment, that disturbed space relations can be effectively reorganized in experience. The next step is to determine how such a reorganization is effected—what factors coöperate, what their relative influence is, and what their mode of functioning.

II

APPARATUS AND METHOD

Stratton's method, while admirable for his purpose, is far too complex for ours, and would involve too much fatigue and inconvenience to be employed with any considerable number of subjects. The essential nature of the process in question would be the same were the observers to be subject to the disturbed con-

ditions for only a short time each day, instead of continuously. If under such circumstances reorganization could be secured at all, it would permit of definite experimental control and would yield results just as significant for the general theory of space perception as would those obtained in more complex situations, in which exact control would be almost impossible.

We finally determined to use, instead of Stratton's 180 degree reversing lenses, a pair of prismatic glasses which produced an angular deviation of the visual field of about 21 degrees. These the subjects wore for 20 minutes each day, while working at the simple task of localizing, by reaching movements, objects arranged in definite positions. We found that under these circumstances there was a gradual and progressive tendency, more or less completely fulfilled according to experimental conditions, to overcome the wide initial visual distortion and to localize the objects more and more accurately. We then planned a series of experiments with the object of determining first, what are the sensory or other factors concerned in this particular process of readjustment; and second, what is the relative efficacy of the different factors involved.

The glasses used in our experiment consist of two 40 degree optical prisms producing an angular deviation of about 21 degrees. These were mounted in a light aluminum frame in such a way that they can be easily adjusted back and forth; or turned in any one of the four directions—right, left, up, or down. The prism used for the left eye consists of two 20 degree prisms combined, and produces a deviation slightly greater than the prism for the right eye, but not great enough to cause any trouble in combining the images for the two eyes. Throughout the experiments we were thus able to work with binocular vision, in which respect our conditions are superior to those of Stratton, who relied on monocular vision.

Careful measures were taken to insure that no light should enter the eyes of our subjects except that which came through the prisms. The light frame in which the prisms are mounted, is so shaped as to fit closely over the nose. To the upper and lower

sides are glued fitted pieces of black cloth-covered felt about a fourth of an inch thick, so shaped as to extend back and rest against the forehead and cheeks. To the ends of the frame are attached double flaps of black cloth which extend back toward the ears. The glasses were kept in place by an adjustable rubber band extending from the ends of the frame around the back of the subject's head. When they were put on, a piece of cotton was slipped under the lower part of the frame, over the cheeks and nose, in such a way as to fill up any space that might remain. Thus only light that came through the prisms was admitted to the eye.

At first subjects usually felt somewhat disturbed, on account of the strangeness of the prismatic effect, and the unusual limitation of the visual field by the frame of the glasses. But this feeling soon wore off, and after two or three sittings they reported feeling quite natural and at ease. The glasses are fairly light and not uncomfortable. It is easy to obtain a relatively clear single image of any object by turning the head in the proper direction.

While wearing these glasses the subject was set to work at a task offering favorable conditions for the formation of a new spatial coördination. He was seated at a table facing a row of objects which he was to localize by reaching out with his right arm and right index finger. (See Plate I.) These objects, small electric buzzers (C), are suspended at about the level of the subject's eyes from a horizontal iron rod (R) elevated 35 cm. above the top of the table. The rod is held in place by three wooden uprights fastened to a board at the back of the table which joins two other boards at the ends (G, G) to form a box-like upper extension of the table, open in front.

Now with the prisms adjusted to cause a deviation to the right, a buzzer which was really directly in front of the subject appeared to be about 25 cm. to his right, and in pointing it out he touched a point 25 cm. farther to the right than the buzzer actually was, there being no incentive to correct to the left. In order that the subject might not see his arm when reaching for the buzzers, and thus be tempted to correct the obvious error, a wooden cover was provided for the box-like extension, attached at the

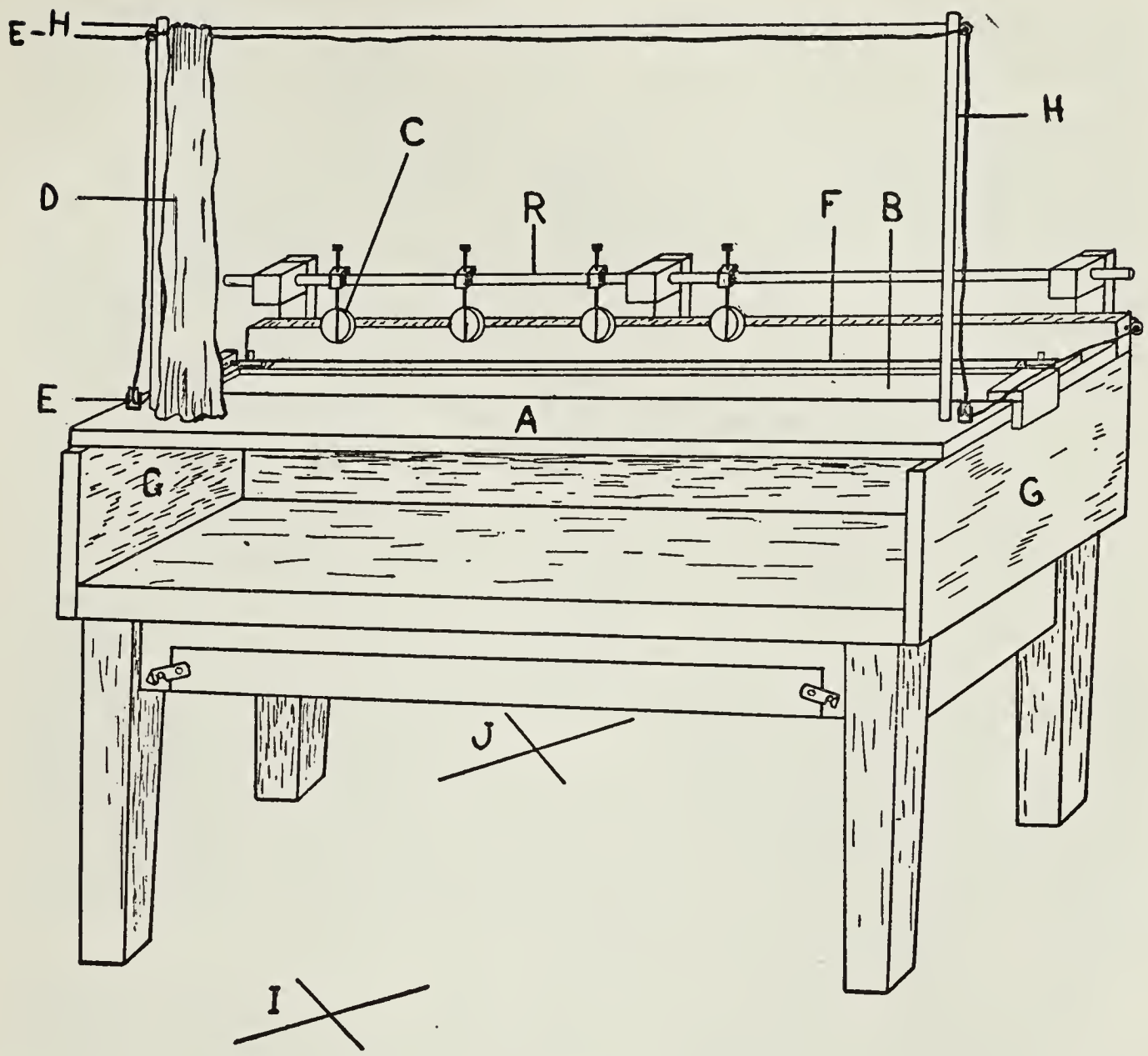

PLATE I

ends to the top of the end boards (G, G). The subject, seated in the chair with base at I, thus looked *over* the cover at the objects (C) but localized them by reaching out his arm *under* the cover. When leaning back in the chair between trials, the subject was prevented from seeing his body by the frame of the glasses. Hence at no time while wearing the glasses was any part of the subject's body visible to him.

In certain of the series it was necessary that the position of the subject's finger be observable by the experimenter, seated back of the apparatus, while not by the subject himself. Therefore just beneath the buzzers there is a narrow slit, between the cover and the back of the extension, through which the experimenter could look down and note the position of the sub-

ject's finger. It was necessary also that this slit be widened at times in order that the subject might at the end of his reaching movement see his finger and thus note his error; or in order that the buzzer might be lowered down through the slit in such a position that the upper half would be visible to the subject, and the lower half, although beneath the cover and invisible, could be touched by the subject as he reached out. To provide for the three different widths of the slit thus necessary, the back part of the cover is made adjustable, or capable of being moved from back to front and vice versa, to widen or narrow the slit. It is desirable that this movable part of the cover have a thin edge and a smooth under surface furnishing no tactual clues of position, and so it is made of a strip of glass about 18 cm. wide, with the upper surface painted black. This strip (B) is set in a sliding wooden frame which can be pushed part way back under the front or wooden part of the cover (A). The distances by which this adjustable strip in its frame shall be moved to front or back is regulated by means of brass stops at the ends of the frame. In this way the strip can easily be set for any one of the three different widths of the slit desired.

The position of the buzzers along the rod and their height above the table can be easily changed. The detail diagram (Plate II) shows how this can be done. Each buzzer is clamped to the lower end of a long screw. To this screw is attached a brass clamp through which the buzzer can be adjusted up and down. The clamp fits over the iron rod and can be securely attached to it at any position by means of a small thumbscrew at the back. The buzzer can thus be raised (after loosening the thumb screw and the small nut) by lifting the clamp off the rod, and setting it toward the bottom of the screw. It can be lowered by setting the clamp toward the top of the screw. The clamp can be put in the same position on the rod, or in another position, and screwed in place as before. In the figure one buzzer is shown raised and another lowered half way through the slit. In actual practice all the buzzers are at the same height in the same experiment.

The buzzers are connected with two dry cell batteries kept in a box attached to the back of the apparatus. They are operated

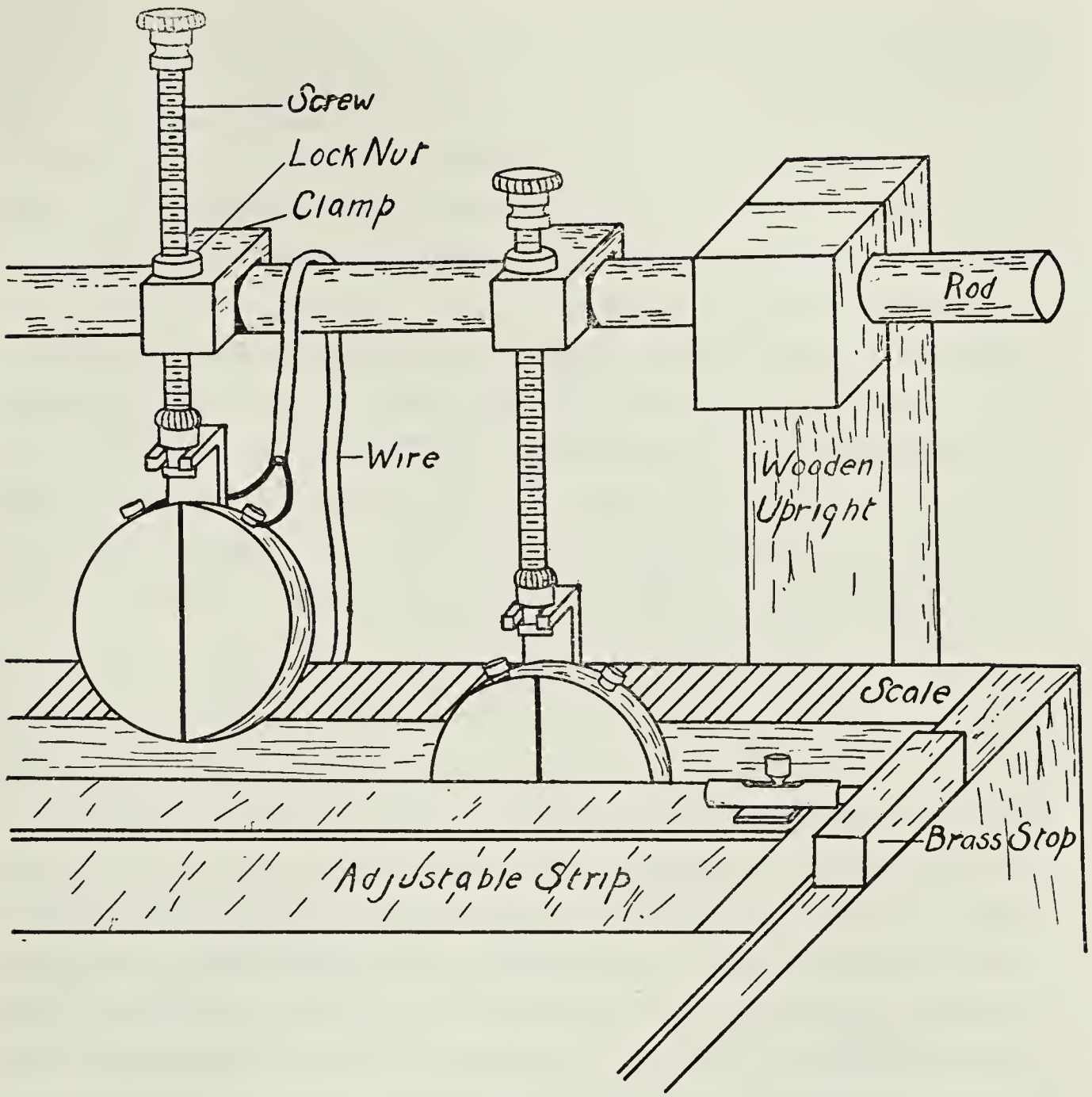

PLATE II

by means of a row of push buttons arranged near the battery box. The light flexible wires from the buzzers hang inconspicuously down over the rod at the back. Also at the back of the table, to the experimenter's right, is a shelf for her use in recording data, and to her left a small shelf for extra buzzers. None of these parts of the apparatus are in view of the subject.

In most of the experimental series it was necessary that the subject should not be able to perceive the extent and direction of his error by noting the position of the experimenter's head when she bent over to get the record. To prevent this, two different methods were used. At first the subject was merely asked to close

his eyes as soon as the localization was made. This proving unsatisfactory, a black curtain (D, Plate I) was arranged to shut off the view of the buzzers after each localization. It operates between two vertical iron rods (H, H) by means of a system of rings, screw pulleys (E, E), and cords, which enable the experimenter to manipulate the curtain easily and quickly by the use of one hand behind the apparatus.

The chair in which the subject was seated is a small armless swivel chair of adjustable height, easily rotated. It was kept in the same position throughout the sittings, 15 cm. in front of the line connecting the front legs of the table, the center of it 12 cm. to the left of the mid-point of that line. The experimenter sat on a high office stool back of the apparatus and just opposite the subject. (Base of stool shown at J.)

A few minor points will complete the description of the apparatus. The iron rod is covered with rubber tubing to prevent jarring and modification of the sound of the buzzers. Just back of the board which forms the back of the extension, is painted a centimeter scale (reading from right to left from the subject's point of view) on which the position of the subject's finger at any localization can be read off by the experimenter. A vertical black line painted on the front face of each buzzer makes it more easily localizable. The whole apparatus with the exception of the buzzers is painted a dull black, the lines of the scale being marked in white.

The dimensions of the chief parts of the apparatus not already given are as follows: top, 60.5 cm. by 121 cm.; height, 78 cm.; height of cover above table, 27.5 cm.; diameters of buzzers, 4.5 cm.

The general order of procedure in the experiments was about as follows. On the first day the subject was given a preliminary test for accuracy of normal localization of the buzzers by hand movement, without the glasses. On the second day he wore the glasses, and was instructed to localize the buzzers in the same manner as at the first sitting, *as they appeared to him,* disregarding the fact of distortion. Under these conditions it was found that the subjects, influenced consciously or unconsciously by certain sen-

sory or other factors, showed in succeeding sittings a tendency to approach closer and closer to the actual or normal standard of localization. For instance in the first day's sitting with distorted vision subject R. reacted on the average 18 cm. to the right of the actual position of a buzzer; in the second day's sitting the average distance from the true position was only 16.5 cm.; in the third, only 14.5 cm., the fourth 12 cm., and so on.

The original aim of the experiments was to continue the sittings for each subject either until he had completely "overcome the effects of the distortion", as happened in many cases; or until he had reached the limit of improvement. Since it was impossible for many of the subjects to continue with the sittings until such a limit had been reached, the latter requirement had to be given up. But all the subjects whose results are considered in the group comparisons either "overcame the effects of the distortion" in less than 10 sittings, or continued until 10 sittings with distorted vision had been taken.

The time of day for the sittings was kept constant for each subject as nearly as possible, and was very rarely changed. In general each subject took one sitting a day, six days a week, although occasionally it was necessary to omit two days out of the seven. Each sitting lasted exactly 20 minutes. In that time 20 localizations were made, five for each of four different positions of the buzzers along the scale, the interval between the "localizations" or trials being 60 seconds throughout all the experiments. Such a long interval was made necessary by the circumstance that in certain of the series adjustments of the apparatus which required that much time had to be made in the interval.

During the interval conversation between the subject and experimenter was permitted and in fact encouraged, first that the subject might feel at ease and natural, and second that he might get the habit of making his localizations in an unstudied and automatic manner just as he would reach out for an object under the conditions of everyday life. The effort was made to get each subject to give himself up freely to the conditions of the experiment. The directions called for a disregard of the fact of

distortion, and required the subject to react, although carefully, without self-consciousness or critical analysis of the nature of the localizing movement or of the possible error. Introspective comments were not asked for until after the final sitting, but remarks made spontaneously were carefully noted during the series; and if a peculiar tendency in the results developed at any time a question was put by the experimenter relative to the subject's attitude or understanding of the directions. Unusual bodily conditions—of extreme fatigue, excitement, etc.—were reported and recorded by the experimenter.

In all 72 subjects were used in the main experiments—five being Instructors in the Department of Psychology of the University of Chicago, 40 graduate students in the University (most of these in the Department of Psychology) and 27 upperclassmen taking a course in psychology. The writer conducted all of the experiments in person, except that at two different times of emergency fellow graduate students, Miss Dorritt Stumberg and Miss Katherine Ludgate, very kindly helped out by each giving three or four sittings to two subjects already started in a series. The writer herself acted as subject in all the experimental series possible, WHILE others acting as experimenter, and with conditions as nearly like those for the other subjects as could be arranged. In this way she took series A-1, B-1, C-2, and D.

The experiments here discussed extended over a period of about 12 months.

III

DESCRIPTION OF EXPERIMENTAL SERIES AND RESULTS

There has been much disagreement concerning the relative efficacy of the various modes of sensory reaction in the development of space habits. Particularly has this been the case with respect to sight and touch (including kinaesthesis). Whether or not hearing is a "spatial sense," or may contribute anything to the development of an organized system of spatial reactions, is also a much disputed question. Taste and smell are almost

universally held to be of negligible significance in this respect. Our investigation, therefore, has to do with the relative efficacy of hearing, sight, and touch, as factors contributing to the formation of the new spatial coördination developing under the conditions of our experiment.

There were five main series of experiments. The first (A) was given as a standard series for purposes of comparison with later series. Records were secured from a group of subjects showing their manner of localization of the buzzers from day to day, with distorted vision, but without the sensory clues the influence of which was later to be tested. For this series the slit at the back of the cover was so narrowed that the subject could not see his finger after reacting, nor touch the buzzer. The buzzer was not sounded as the signal for reaction, but merely pointed out by finger movement.

In the second series (B), designed to test the efficacy of sound, conditions were exactly as in the first except that the buzzer was sounding. In the third series (C), to test the efficacy of touch, the buzzer was lowered half way down through the slit so that when a correct localization occurred there would be contact of the finger with the buzzer. In the fourth series (D), to test the efficacy of sight of the localizing finger, the slit was widened so that the finger tip could be seen after the localization had been made, and the buzzer was raised high enough to prevent contact. In the fifth series (E), designed to test the influence of tactual-kinaesthetic sensations from the left arm, no buzzers were used. The subject extended his left arm *over* the cover, bending the index finger down through the slit, and localized this finger as the buzzer was localized in preceding series, by a reaching movement of the right arm under the cover.

STANDARD SERIES

1. Effect of Knowledge of Experimental Conditions

a. *Experiments With Knowledge*

For the standard series, four buzzers were set along the rod at the positions 53, 66, 79, and 92 on the scale. The total length

of the scale being 20 cm., this means that they were set toward the left end, in such a position that they were directly in front of the subject. Distorted, they appeared shifted about 25 cm. farther to his right. On the first day the subject was given 10 trials for normal accuracy of localization of the buzzers, without the glasses. At the second sitting he began the series with distorted vision. The experimenter first instructed the subject as to the proper position of the chair, and then placed his right arm in front of him more or less parallel to the edge of the table. She told him that at the signal "Ready" he was to assume this position, but not to feel that the position was to be rigidly defined—that the only object was to get a uniformly free sweep of the arm. The subject was told also that he would work in ignorance of the purpose of the experiment, and was cautioned not to talk to other subjects who had finished, about that purpose. Then he was given the following instructions, typewritten, and asked to study them carefully:

"When I point out one of these four buzzers by placing my finger on it, localize it as in preceding series without the glasses by a direct movement of the right index finger to the point just below the midpoint of the buzzer indicated. The glasses will give a distorted view of the buzzers, but pay no attention to this fact in making your localizations, simply taking pains to localize the buzzer as accurately as possible *as it appears to you*. You will have no means of judging the accuracy of your localizations, so pay no attention to the possible nature of errors, but reach out directly to the buzzer, in a natural and automatic manner, concentrating your attention on the sight of the buzzer. In making the localizing movement, move your head and body freely, as you choose.

"When you have touched the board, close your eyes and keep your finger in place until I say 'All right.' Then relax in your chair and open your eyes if you wish. When I say 'Ready' assume your former position with your arm in place ready to react as before. There will be one trial every 60 seconds, and the stimuli will be given in irregular order. You may converse on indifferent topics between trials, but at the signal "Ready", which will be

given two seconds before the stimulus, all conversation will cease."

After the subject had read these instructions the glasses were put on him by the experimenter and he swung around in the chair, facing the buzzers. The point is to be emphasized that the subject, in making his localizations, had no direct sensory means of judging their accuracy. The buzzers were not sounding. The slit was so narrowed that the subject could not see his finger when he had made a localization. In order that he might not gain knowledge concerning the direction and extent of his error through noticing the position of the experimenter's head when she bent over to take the record, the instructions are explicit that the subject shall close his eyes as soon as he has touched the board, and not open them until she says "All right" which means that the position of the finger has been noted and that the experimenter has assumed her usual position again. Great care was taken in regard to this point.

While the subject was not told what was the direction of the deviation, in most cases he found it out during the first sitting, being familiar with the normal appearance of the apparatus and knowing how the prisms were set in the glasses. But there were no clues to enable him to realize the extent of his error from day to day. The fact that there was no such realization, is proved by the comments of the subjects, who confessed themselves in the dark and frequently made absurd estimations of the amount of their errors. But this group did work, it must be noted, with some knowledge of the experimental conditions.

The results of this first series with distorted vision are surprising. They indicate that there is from the first localization, a progressive tendency on the part of most subjects gradually to approach the actual position of the buzzer. In general the rate of readjustment is slow. Of the initial linear deviation, which in this group averages for the four buzzers 21.1 cm., only 40.5 per cent on the average was recovered in the first 10 days. However for the six subjects in the group who were kept at the task until the limit of improvement was apparently reached (until at least five sittings in succession showed no improvement) the total percentage of readjustment amounted to 59 per cent over

the initial deviation. This means that in spite of the fact that these subjects had no sensory clues as to the actual position of the buzzers, they still "readjusted" to the new visual situation, to the extent that they learned to localize the buzzers at a point about 60 per cent nearer their actual position than they had localized them at the beginning of the series. In other words we have an ascending curve instead of the straight line that might have been expected.

A glance at Figure I, showing graphically the results of subject H. R. K., which are typical for the first group of experiments, will make the situation clear. The numbers on the ordinate refer to positions on the scale in centimeters, and those on the abscissa to successive days' sittings. The four straight lines at 53, 66, 79, and 92 represent the actual positions of the 4 buzzers. Buzzer number 1 (53) is to the subject's right; buzzer number 4 (92) to his left as he sits at the apparatus. The curves which approach the lines show the progress of the subject from day to day, each point on a curve representing the average of the five trials for that buzzer taken on that day. The line and curve for buzzers 92 (4) and 66 (2) are dotted, while those for 79 (3) and 53 (1) are unbroken.

In seeking for a method of treatment of the results which should be suitable for all the series of experiments in our investigation, we finally decided on the following plan. The measure of the amount of readjustment effected in any case is the distance in centimeters still "unrecovered" when the subject has reached his highest point of readjustment. In the case of any subject, then, this distance will be obtained for each buzzer by substracting the average of the five localizations made at the highest point of readjustment, from the average of the five trials for normal visual accuracy made for the same buzzer. This will give the number of centimeters that would have to be "recovered" before the subject would again attain his normal accuracy in localizing the buzzer. Such a linear distance yet remaining to be "recovered" we will call arbitrarily in our discussion of results, "the remainder." For example subject H. R. K., beginning with a linear deviation of about 25 cm. for buzzer number 1, had reached as her high point of readjust-

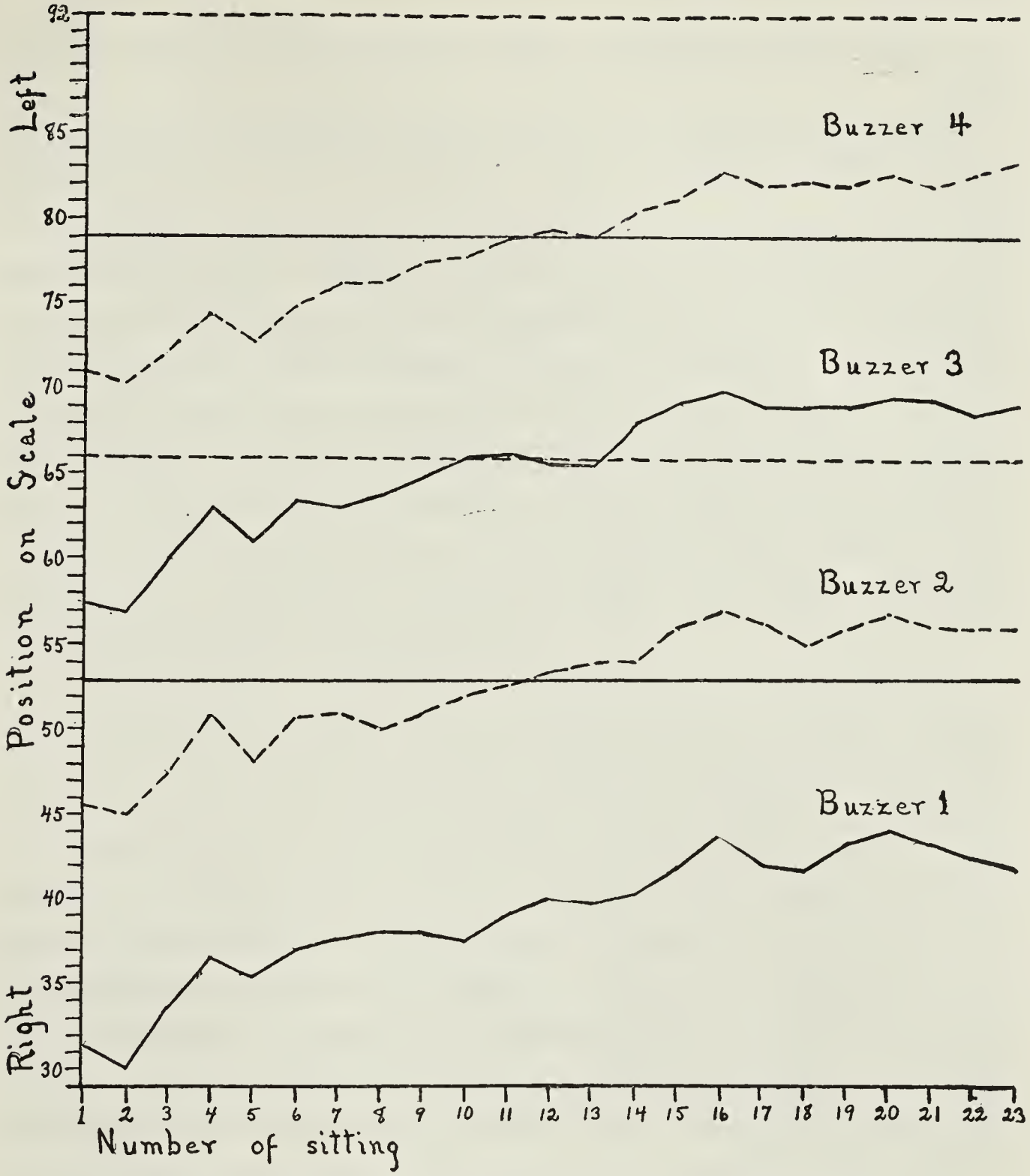

FIG I. Readjustment of Subject H. R. K. Standard Series

ment for that position, on the 19th day's sitting, the average position of 44.5 cm. Her average normal localization for buzzer 1 is 55.5 cm. Her remainder for buzzer 1, then, for the whole period of the series, is 55.5 cm. minus 44.5 cm., or 11 cm.

In addition to thus measuring the amount of readjustment by the remainder, or remaining distance from the normal standard of accuracy, it is also convenient at times to use as a measure the per cent of the linear deviation which has already been recovered. Such a measure is, however, far less significant for comparative discussion than the remainder, for the reason that it is based on

the initial linear deviation, which varies greatly among individuals.

While theoretically the glasses should produce a standard objective linear deviation which is the same for all individuals, practically, under the conditions of our experiment, they do not. This is because in the first place the position of the head is not constant, and the linear deviation varies somewhat with every change in the distance from the buzzer to the eye, and in the angle formed by this line with the scale at the back of the apparatus along which the linear deviation is measured. It was not possible to keep these factors constant by fixing the head position, because among the series is one involving auditory localization, for which free head movement is essential; and general conditions had to be constant throughout the experimental series.

A second reason for individual variation in linear deviation may be found in the variability of the angle of incidence or the angle at which the rays of light from the buzzer strike the prisms. According as the buzzer is viewed through the large or the small end of the prisms, there is a difference of several centimeters in linear deviation. As a matter of fact with the direct forward fixation which was naturally maintained in localizing the buzzers the change due to variation in angle of incidence would be so slight as to be practically negligible. It must be reckoned with, however, as a factor tending to produce a slight amount of variation from individual to individual as well as within the results of any one subject.

Thus it is impossible to determine a standard general linear deviation upon which to base per cents of readjustment for all subjects. It might seem practicable to base the per cents of readjustments for an individual on his own initial linear deviation. But it is not possible closely to determine even this individual deviation. Several trials would be needed for a reliable determination. Readjustment, however, begins after the very first trial, and indeed in some series even prior to it. Again, the head position even of one individual, may change somewhat from trial to trial for the same buzzer.

It is clear, then, that for purposes of group comparison the

remainder, rather than the per cent of readjustment, is the more reliable measure of progress. It will be helpful, however, to deal with per cents in treating individual results, and in broad general discussions.

To find the per cent of readjustment for any individual we must find the total distance between the *initial* localization with the glasses and the place of normal localization, and determine what per cent of that distance has been recovered at the highest point of readjustment. In the first two series, A and B, the five localizations of a buzzer in the first sitting are about the same, and so to find the initial deviation for individuals in those series we will subtract the *average* of the first five trials for a given buzzer, from the average of the 10 trials for *normal* accuracy of localization of the same buzzer.

In series C, D, and E, however, readjustment is so rapid that the average for the first five trials for a position would already represent an advance of as much as several centimeters over the initial localization for that position. Hence in these later groups we are compelled to find the initial deviation for a given position by subtracting the first trial only from the average normal localization. This will mean greater variability in linear deviations, since one trial is not a sufficient measure of accuracy. Here too there will be considerable variability in the amount of initial deviation for the four different positions, owing to the fact that readjustment is already in progress after the first localization among these four. For the last three series, then (C, D, and E), since the per cent of readjustment based on initial deviation will be particularly variable and thus unreliable for comparative purposes, the usual basis of comparative discussion will be the remainder.

Individual and group results for series A-1-a are given in Figures I and II and in Table I (p. 20). Nine subjects in all served in this group. This includes the writer whose peculiar knowledge of the situation makes her results not strictly comparable with the others, and one subject who was forced early to discontinue the sittings. This leaves seven whose results are considered in computing group averages.

TABLE I

STANDARD SERIES

Showing results for Group A-1a *(with knowledge) and Group* A-1-b *(without knowledge)*

Subjects	No. of Sittings	Visual Acc. 53	66	79	92	Av.*L.D. 1st 5 trials	Av. Rem. 10 da.	Av. Rem. Total	Per cent Readj. 10 da.	Per cent Readj. Total
Group A-1-a										
H.L.K.	12	55.1	69.3	82.7	94.7	18.7	9.9	8.8	47	53
M.R.G.	25	52.8	65.7	79.5	92.7	20.7	12.5	12.2	40	41
O.B.B.	22	52.8	65.7	79.2	92.7	20.5	16.9	9.5	18	54
H.R.K.	23	55.5	65.5	78.8	92.4	21.9	14.7	9.7	33	56
M.F.R.	19	53.6	67.7	81.0	93.8	18.4	11.7	8.7	37	53
W.A.O.	27	55.7	68.4	81.1	93.1	16.8	9.4	3.5	44	79
P.R.	10	....	....	....	....	17.1	12.4	....	28	..
Average		54.2	67.0	80.4	93.2	19.1	12.5	8.7	35	56
Group A-1-b										
M.O.W.	28	....	....	....	....	16.9	13.7	10.6	19	37
D.S.	15	....	....	....	....	22.6	9.8	9.7	56	57
R.R.	11	....	....	....	....	12.4	7.8	7.5	37	40
M.McF.	35	....	....	....	....	18.9	11.3	8.6	41	54
Average		....	....	....	....	17.7	10.6	9.1	38	47

* L.D.—linear deviation.

The four curves of H. R. K., presented, as typical ones, in Figure I, show a gradual and steady slope, extending over 16 days' sittings, after which for eight days there is only a slight wavering with no improvement. There is a striking correspondence in the shape of the curves for the four buzzers, a slight change in one curve for a day's sitting almost always corresponding to a similar change in the other three curves. These facts indicate that whatever causes are at work to produce the "learning," operate in a regular and consistent manner. The relatively straight line from the 16th to the 23d sitting seemed at the time to indicate that the subject had reached the limit of improvement, and so the sittings were discontinued. Later experiments would indicate that this may have been only a "plateau," and that another period of improvement might have set in. The drop in the curves at the fifth sitting may have been due to the unusual fatigue reported by the subject at that time. Of her initial linear devia-

tion of 22 cm., Table I shows that H. R. K. recovered finally 56 per cent, with a final remainder of 9.7 cm.

Questioning at the close of the series with distorted vision revealed the fact that H. R. K., while aware that the distortion was to the right of the actual position of the buzzers, was not aware either of the extent of her error or of the fact that she was gradually, as the sittings progressed, reacting farther and farther to the left. She could imagine no factors that could have caused her thus to change her localizations, beyond the mere fact of knowledge of the direction of the distortion.

Similar in type to the results of H. R. K. are those of H. L. K., M. R. G., and M. F. R. The curves for all of them (not given in the figure) show the same gradual and steady progress and the same correspondence in the curves for the four buzzers. They differ in rate and amount of readjustment effected, M. R. G's progress being very slow and amounting to only 41 per cent of recovery of his initial deviation after 25 sittings, while H. L. K's progress (the most rapid in the group) amounted to 53 per cent of her initial deviation in the course of only 12 sittings. If it had been possible to continue H. L. K's sittings, it seems likely that she might have finally entirely overcome her remainder of nine cm., although it is true that for the last five of her sittings she showed no improvement.

The results of two subjects in this group, O. B. B. and W. A. O., require special discussion. They are presented graphically in Figure II. In this figure as in succeeding figures only two curves are shown although curves for all four buzzers were originally plotted. The curves for the four positions are so nearly alike that it was not thought necessary to present them all here. In each case, then, curves for buzzer No. 1 (53) and buzzer No. 4 (92) only are given (except for Figure III where curves for No. 2 and No. 4 are given). These two are taken because of the four they differ most widely in the case of practically all subjects. (It will be noted that the curves for buzzer No. 4 almost universally show relatively closer approach to the actual position of the buzzer, than curves for buzzer No. 1. In general the farther to the left the buzzer, the greater the degree of the apparent readjustment as

indicated by the curves. This fact can be explained on mathematical grounds, as set forth in the discussion of experiment A-2-b, on page 42. In this figure the numbers on the abscissa again refer to the numbers of the sittings, but the numbers on the ordinate represent this time the number by which the localizations for each day deviate on the average from the true position of the buzzer, indicated by the straight dotted line. Thus the curves show from day to day a gradually decreasing deviation. In every curve presented in the figure the first point, for the first day's sitting represents the deviation of the actual initial localization for that particular buzzer, and not the average of the five trials for that day. This is done to give a true idea of the actual range of the deviation. A truer picture of succeeding progress, however, because more measurements are considered, is given by letting the point for each day represent the average of the five trials for that day, and so the second and succeeding points on the curves each represent the average of five trials for a particular day's sitting.

The method of plotting used in Figure II holds for all the succeeding figures except for III and IV where special exceptions are noted. It will help in understanding the figures to remember that the lower curves represent buzzer 1, or position 53 on the scale, to the subject's right; and that the upper curves represent buzzer 4, or position 92 on the scale, to the subject's left.

The results of O. B. B. are peculiar, in that unlike the other subjects discussed his improvement was not gradual and steady from sitting to sitting. In his case, after a short rise from the first to the third sittings, the curves settle down into relatively straight lines showing no further improvement until the 12th sitting, after which they rise rapidly to the 17th before terminating in the five day "plateau" which may or may not mark the limit of improvement. Reference to Table I shows that while within the first 10 sittings his average remainder was as large as 16.9 out of an average initial deviation of 20.5, by the end of the 22d sitting it was only 9.5. Otherwise stated, for the first 10 sittings the readjustments effected was only 18 per cent, but at the 17th sitting it had jumped to 54 per cent. It is results like

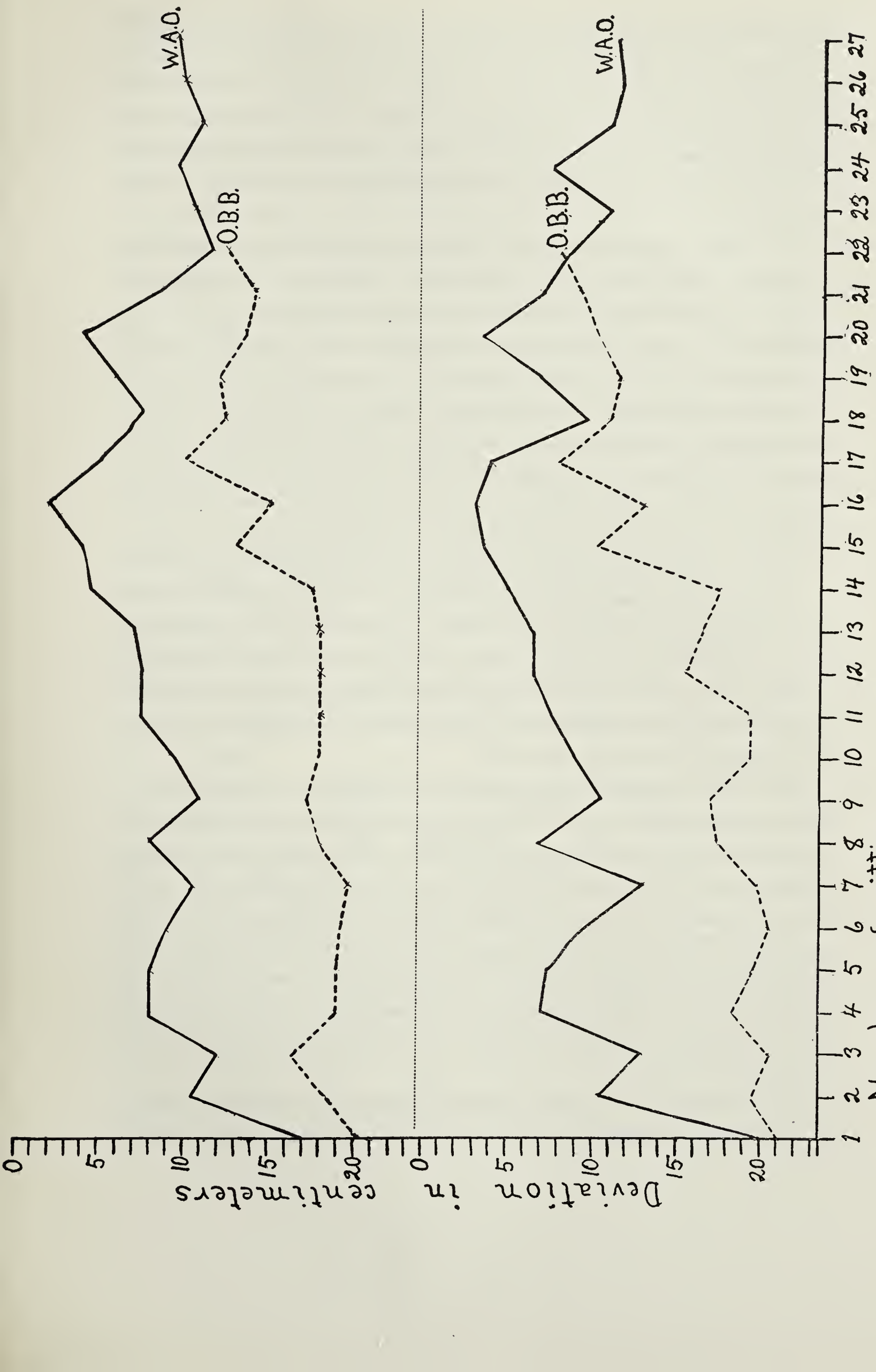

FIG. II. Standard Series. With Knowledge.

these of O. B. B. which first made the experimenter doubt the validity of any criterion for deciding when a subject has reached the limit of adjustment. Later results in this and other series confirmed this doubt and suggested that in every case there was a genuine possibility that if the subject only kept on long enough, he would finally completely readjust himself to the new visual situation.

O. B. B's comments as the sittings progressed are suggestive. Remember that there were no obvious clues by which he could judge the position of his finger at any localization. In the first sittings he reports feeling very uncertain and "helpless" while reaching out. From the ninth sitting on he reported feeling more confident, although he didn't know why he should be. At the 12th sitting (when in fact the first objective indication of the rapid rise appears) he reports "Feel at home now—not lost as I was at first," and "I bet you I am not far off from the true position." (As a matter of fact he was still 16 cm. off!)

At the 18th sitting when he had reached his smallest remainder (9.5 cm.), he reports "I feel perfectly at home, but don't know what I'm doing." When questioned at the end of the experiment, he was unable to state just what made him feel as he did. While aware of the fact that his manner of localization was changing, he had not been conscious of the clues on the basis of which this change in reaction occurred.

The other peculiar case calling for separate consideration is that of subject W. A. O. These curves rise, not smoothly, but in a rather zigzag fashion, until at the 16th sitting the average remainder is only 3.5 cm., and for two of the buzzers the curve actually meets the line, showing complete readjustment for these positions. This is unusual progress. But the peculiar thing is that at this point the curves begin to descend again, until by the 26th sitting W. A. O. has apparently unlearned all that he learned! By this time he is again within five centimeters of his initial deviation.

The subject's comments as the sittings progressed may help to explain this unusual situation. During the fourth sitting (which

marks a high point in the curves) he says "I feel more and more confidence that I am hitting these, but don't know its source." At the next sitting (fifth) he reports that he knows the direction of the error—to the right. Once in awhile he has, because of leaning farther back from the table, obtained a glimpse of his sleeve and the direction of his arm in reaching out for the buzzer. This gave him the clue. He has also seen, two or three times, the beginning of the experimenter's movement to the right to note the position of his finger. At the 16th sitting (the point of greatest readjustment) the report is "The thing seems much more natural. Distances to the right don't seem so long, or to the left so short, as at first . . . This leads me to think I'm adjusting or learning to react naturally." But this "natural" reaction he thought was to a point in each case a good number of centimeters to the right of where the buzzers actually were. With the 17th sitting the downward slope begins. At the 18th, 21st, and 22d sittings he reports being unusually tired and sleepy—"Am consistently getting too little sleep these nights." At the 22d sitting he speaks of having been self-conscious lately and more uncertain because of hearing remarks from the experimenter and Professor X about his "queer" record. At the 23d sitting he says "I feel that I am doing well. I reach to the right so it feels a long distance—that's the way it has been feeling—it seems farther than it looks."

Now on the face of it, it would appear that W. A. O. was influenced unconsciously by the mere knowledge of the fact of deviation to the right, gradually to approach the actual position of the objects, until he had practically overcome the deviation. At this point (16th sitting) he reported such confidence in the naturalness of the reactions that the experimenter questioned him more closely than she usually questioned subjects, concerning the extent to which he had been following the directions to *ignore* the fact of distortion. This, it would seem, made him self-conscious; and when on the next day his fatigue caused a natural slump in the curves, the fact that he thought the experimenter "seemed worried" at his record, increased his self-

consciousness. From this point his determination conscientiously to *ignore* the distortion to the right simply meant that it was emphasized in his mind, and his later reactions were influenced by the unconscious tendency to react farther to the right than he had been reaching. Whether or not this is the true explanation is a question.

Consideration of group A-1-a as a whole brings out some interesting points. In the first place while a general tendency to build up a new spatial coördination is apparent, there are well marked individual differences. Of those who did show a decided readjustment, the amount varied from an average total remainder of 12.2 in the case of M. R. G. to as little as 3.5 in the case of W. A. O. One subject, the writer, showed only a small amount of wavering in her curves, and no definite tendency whatever to readjust. Another subject, P. A. R., made no really significant advance within the 10 sittings he took, and it is a question whether like O. B. B. he would have shown a spurt of progress later had he continued the experiments. Speaking in terms of per cents of readjustment, of the eight subjects who continued presumably up to the limit of improvement, six showed a per cent of readjustment of over 50, while one attained only 41 per cent and one (the writer) remained at zero percent. The highest per cent was 79 and the average *total* per cent was 56. The average per cent for the 10 day period was 37.

Not only in amount but also in rate of adjustment are marked individual differences apparent. While in general the curves show a rapid increase for the first three sittings and then a gradual increase up to the "plateau" which terminated the sittings, one set, those of O. B. B., shows after the initial rise a long level stretch and then a sudden rise. Another, that of W. A. O., exhibits a gradual but quick approach and then a retrogression. One set of curves, those of M. R. G., drags out over 25 sittings and then shows a readjustment of only 53 per cent. H. L. K's per cent within a 10 day period is 47, while O. B. B's is within the same period only 18.

It remains now to consider to what extent the subjects were aware of the direction and amount of the deviation and what

may have been the effect of their attitude toward the experiment. In the first place all knew that the direction of the deviation was to the right. At least one knew before starting, through noticing the position of the prisms in the frame, but most of them became aware of it only after the sittings were under way, through noticing the change in length of the reach to the right, as compared with the corresponding movement in the previous normal series. All conscientiously aimed to ignore this fact of distortion in making their localizations, and some were unaware that they were making any readjustment. M. R. G., for instance, who estimated quite well the extent of his initial error, drew a diagram after his seventh sitting to show that he must be hitting in the same place each time. Most of the subjects felt each time that the finger was just beneath the buzzer. In this respect H. L. K. is an exception. When she was making a localization it seemed to her that she was touching the right place, but as soon as she closed her eyes her finger seemed out of place. Toward the end of her sittings she reported feeling more natural—that her finger seemed less out of place. This is due to the fact that when she first started she retained the kinaesthetic set from the preceding series, and felt clearly, as most of the other subjects did not, the difference between that and the different "feel" due to the deviation to the right. It is of interest here to note that H. L. K's progress was the most rapid in the group. A. S. F., who after the quick readjustment of about eight centimeters in six sittings had to discontinue the experiment, reported "I feel that the desire to correct to the left influences me, although I try to ignore it." She is the only one to report such a feeling.

The results of the first series of experiments seemed to indicate that knowledge of the direction and extent of the deviation might well be the chief factor in the process of readjustment. We decided, then, to give the same series to a group of subjects so chosen, and with experimental conditions so arranged, as to exclude, if possible, every source of knowledge of the nature of the deviation. The possible sources of knowledge in the series as first given, A-1, together with the way in which these were

obviated with the second group of subjects, in A-2, we will discuss point by point.

1. A knowledge of the direction and extent of the deviation might be gained from other subjects who had finished the series and knew of the conditions. This was avoided in both A-1 and A-2 by strictly cautioning each subject not to discuss the experiment with others.

2. The subject might gain such a knowledge through noticing the sudden shift to the right in the position of objects at the moment of putting on the glasses. In A-1 this was avoided by having the subject turn away from the table and close his eyes while the glasses were being put on. In A-2 the additional precaution was observed of having the subject led about the room with eyes closed and then seated in a chair facing in a direction different from that in which he had previously faced, before the glasses were put on and before he was permitted to open his eyes.

3. Knowledge might be gained through a comparison of the apparatus or general surroundings as viewed through the glasses, with their remembered appearance without the glasses. In A-2 this possibility was obviated by taking as subjects only such students as had never been inside the experimenter's room, seen the apparatus, or heard it described. Hence since the glasses were put on and taken off in another room, these subjects had neither directly nor from the report of others any knowledge of the normal appearance of the apparatus or the room.

4. The subject might learn the nature of his error through noticing the position assumed by the experimenter in bending over to get the record, either through accidentally opening his eyes or through a too quick movement of the experimenter before the eyes were closed. To obviate this source of knowledge the black curtain previously described was used to screen the experimenter's movements while taking the record.

5. The subject might discover the direction of the distortion through retention of the kinaesthetic set from either the previous normal series or the auditory series, and its comparison with the new set due to the deflection to the right. This comparison was

indeed reported as the source of such knowledge by some of the subjects in A-1. In A-2 such a possibility was provided against by having the subject start in with the main series, omitting the preliminary tests without the glasses.

6. Again, the unnaturally long reach to the right might suggest, even were there no preliminary tests, that the distortion was in that direction. To eliminate this possibility in A-2, the extreme right hand buzzer which involved the only long reach upon which subjects had commented, was omitted. This left only three buzzers to be localized.

7. A seventh possibility is that the subject familiar with the effect of prisms might easily reason out both the direction and the approximate extent of the deviation, through the mere observation of the prisms before putting on the glasses. In A-2 this possibility was obviated by not permitting the subject to see the glasses at any time, and by making sure before the sittings began that he had not heard from any source what kind of glasses were being used.

8. Finally, the subject might gain knowledge of the character of the deviation through his unusual tactual-kinaesthetic orientation with respect to the edge of the table and the cover. In other words through feeling of these edges as he sat looking at the buzzers he might find out that the line of vision was not perpendicular to these edges as he might expect, but one forming an angle to the right. The same sort of clues might be gained for some subjects from the contact of the lower part of the board forming the front of the table, with the body or the knees. In order to eliminate these possible clues, several precautions were taken. The lower section of the front board was sawed out in order to prevent contact. The subject was strictly forbidden to make exploratory movements with his hands between trials. At the beginning of the sitting the experimenter put the subject's hands in position in front of him. The first paragraph of the "Instructions to Subject", covering this point, is as follows:

"When seated in the chair, let the right arm lie along the edge of the table, and the left extend out on the table, but not more than 90 degrees to the left. Between trials either keep the arms

in this position, or swing the chair away from the table and let them rest in your lap. At no time make any exploratory movements except when directed to."

The eight sources of knowledge discussed above include all possible ways, we think, in which the subject might gain a knowledge of the direction and extent of the deviation produced by the glasses. They were all eliminated in the series as given to the second group of subjects—series A-2. This does not necessarily mean, of course, the elimination of all possible sensory clues on the basis of which the subject might unconsciously react.

b. *Experiments Without Knowledge.*

Aside from the paragraph quoted above, and a sentence explaining the use of the curtain, the instructions for Series A-1-b were exactly as in A-1. The glasses were put on the subject in the manner described, in an outer room. He was then led into the experimenter's room and to the subject's chair, in which he managed to seat himself by the aid of touch and kinaesthesis. When his hands had been put in position by the experimenter he was permitted to open his eyes. He then began the localizations according to the instructions he had received. In order that these instructions might be thoroughly impressed upon the subject, they were typewritten and he was required to study them before each of the first three sittings.

The trials were given in the same manner as in A-1 except for the use of the curtain. Since only three buzzers were used seven trials each were given in a sitting. This makes the total number of trials and of minutes 21 instead of 20, but such a small difference could hardly be expected to have any appreciable influence on the results.

At the conclusion of the sitting the subject was led out of the room with eyes closed. He was not permitted to open his eyes until the glasses had been removed and put out of sight.

Individual results for this series are given in Table I, p. 20. In Figure III are presented two typical sets of curves, those of subjects D. S. and M. O. W. Since in this series buzzer No. 1

was not used, the two curves given for each subject are for buzzers 2 and 4.

These results are surprising. The subjects in this group, although in at least three cases ignorant by their own later state-

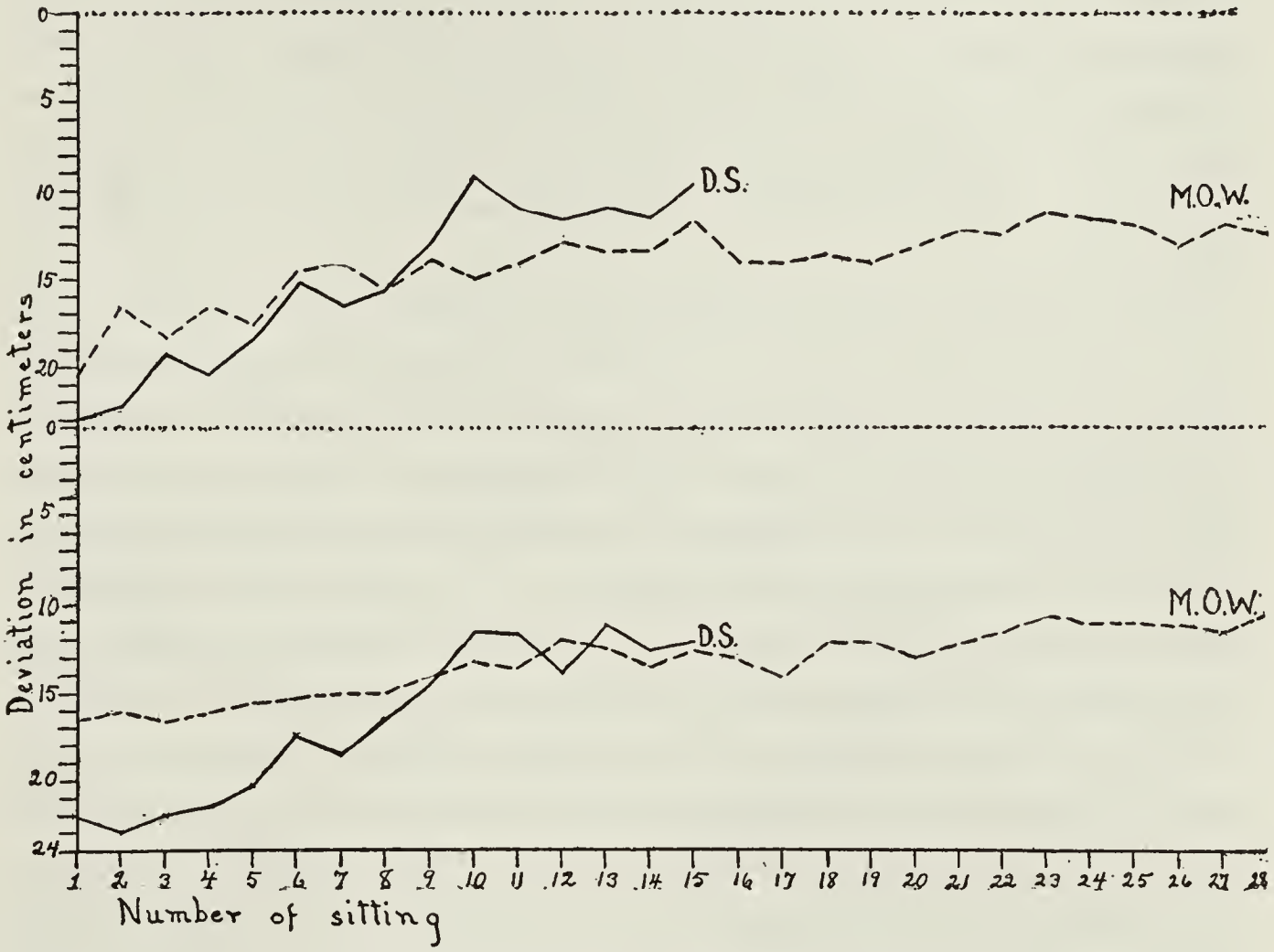

FIG. III. Standard Series. Without Knowledge.

ments of the nature, direction, or extent of the distortion, showed during the first 10 days just as marked a tendency to readjust to the new visual situation as did the subjects in the first group! In fact if we were to consider significant the small difference in amount of readjustment, they showed in the first 10 days more of a tendency, for on the average their remainder is only 10.6 cm., while the average for the first group is 12.5 cm. Even this small difference decreased with later sittings, and so allowing for the slight variation in the experimental conditions, the logical conclusion would be that knowledge of the conditions of the distortion apparently has no effect either on the rapidity or the rate of the readjustment. Comparison of the average curves

for 10 days of these two groups, as shown in Figure X reveals their essential similarity.

The curves for this group show the same consistency and the same sort of individual differences as in the first group. The two longest curves in the group, those of M. M. and M. O. W., show continuous and very gradual progress, extending over 28 and 35 days respectively. M. M.'s results, with 41 per cent of improvement within 10 days and 54 per cent within 35 days, especially seem to indicate that improvement may go on indefinitely.

The comments of individuals are of interest here. R. R. reports that she did not know at all the direction of the distortion, though she had a vague feeling that it was to the left. "I hadn't the slightest idea as to the kind of lenses—I felt I was to the right but didn't know why at all—thought my finger was about one inch to the right of the buzzer . . . I felt I was hitting in the same place all the time . . .For the first few sittings my finger didn't feel right. Later the finger felt just where it landed."

Early in the series M. O. W. found out that there was some sort of disparity from seeing the experimenter in one place when she went to the door and "hearing her talk in another." But at the eighth sitting he reports "I don't know what these things (glasses) are doing. For all I know you may even be behind me, and everything turned clear around." It was only at the 18th sitting that M. O. W. could have guessed something of the direction and the extent of the error, when he unthinkingly reached out his hand over the cover to hand the experimenter his pencil —and of course noticed his error. He announced that he would try not to heed this, and at the end of the long series of sittings felt that it had not influenced him in the least. He was astonished to find that he had not been hitting in the same place all the time.

A distinct illusion that developed in M. O. W.'s case is striking. He took it for granted that when he was seated at the table he was sitting "at right angles to it", with the three buzzers directly in front of him. Therefore when he localized a buzzer, especially the middle one, he thought his finger was striking the board at the back at a right angle. As a matter of fact the buzzers ap-

peared over 20 cm. to his right and hence the finger struck at an angle nearer 45 degrees than 90 degrees. But to him all the time the angle was a right angle, and the tip of his finger seemed pressed squarely against the board. The illusion was made clear when at the end of the series he made a few trials without the glasses. This time his finger actually was at right angles to the board and the tip against it; but he reported a very strong feeling that now the angle was acute, and that it was with the side of the end of his finger that he seemed to be touching the board! The illusion was so strong and persistent that he could not get rid of it. This is an excellent illustration of the relativity of the tactual local sign system.

It is the case of D. S. in this group which is most unequivocal. (See curves in Fig. III.) Hers was the most rapid adjustment, yet she felt all the time that she was hitting to the *left* of the buzzers! "I haven't thought about what the glasses were doing each day—or at all," she said. "They merely made things more hazy . . . Every time I put my finger in place I felt that if I moved a little to the right I'd be more accurate." To her also the three buzzers seemed directly in front. When she was taking a sitting with the glasses after her regular sittings were over and the situation finally made clear to her, she said, "Seem to be reacting as usual. Still I could almost swear I am going to the left of the buzzer each time, although I know from conversation I was going to the right. . . The kinaesthetic clues, though I watch for them now, don't help me."

2. Effect of Position of Body, Head, and Eyes

The results of the second group, A-1-b, show clearly that knowledge of the nature and direction of the distortion is not an essential condition of readjustment. The next hypothesis that seemed most fruitful concerned the effect on the localization of the buzzers of head and body position.

It is reasonable to suppose in the first place—and casual observation confirms the view—that in fixating the right hand buzzers, 53 and 66, the head of the subject was turned relatively farther to the right *than was the body*. This is because under the

conditions of distortion the point midway between the two end buzzers appeared to be about 20 cm. to the right of the main perpendicular axis of the body of the subject, considering him as facing the table squarely. Now the subjects (in view of the auditory series included) were all told to move the head *and body* freely, as they chose. Bu in fixating a point far to the right the head would naturally be turned farther than the body, since we are accustomed to fixate objects with relatively little body movement as compared with head movement. Now the arm and hand might naturally tend to assume a position in line with the central body position rather than that of the head, for the following reason. While wearing the prismatic glasses, the subject, in fixating the buzzers *as they appear to him,* turns his head and eyes about 20 degrees to his right. But the buzzers are in the center of his field of vision, and as he reacts to them, it is with the same "set" that he would have were they directly in front of him. (Cf. M. O. W.'s illusion of position.) Now in the course of his normal experience reacting "in front" has come to mean always reaching out more or less at right angles to the *body*. This association may well persist in the abnormal situation, so that if the head is turned farther to the right than the body, the subject in reaching out for the buzzers "in front of him" as they appear to be, will tend to reach out according to the old habit in front of his *body*. This might well explain a tendency to depart from the initial localizations far to the right, in the direction of the central body position. We might explain the gradual nature of the change by a decrease in attention to the accuracy of the localization as the process becomes automatic.

In the second place the localizing of buzzer 53 involved a reach to the right unnaturally long for most subjects, who always commented on the length of the reach. When an unusual reach in any direction is involved, a reach accompanied by noticeable muscular strain, would not the mere influence of inertia cause a relaxation in the strain of reaching when, as in this experiment, there is no practical check on the correctness of the reaching movement? And might not the tendency connected with the buz-

zer 53 conceivably influence the reaction to the other buzzers in similar degree?

It is clearly possible, then, that the readjustment to the left may be caused first by a tendency for reaching movements to be in line with the central bodily attitude rather than that of the head; and second by a tendency to react in the direction of least muscular exertion. Considering both of these possible sources of influence, might we not expect a subject under normal conditions of vision, to show a progressive "adjustment" to the left in seeking to localize buzzers placed as far to the left as the buzzers *appeared* to be when distorted by the glasses?

Conversely, let us suppose a subject wearing the prismatic glasses, and localizing buzzers placed so far to his *right* that the muscular strain and disparity in head and body position would be to the right in localizing the buzzers as distorted, instead of to the left. Might we not then expect to find such a subject showing a tendency to "readjust" to the right instead of to the left, so that our curves would indicate a tendency to depart from the actual position of the object instead of a tendency to approach it?

a. *Experiments With Undistorted Vision.*

In order to find the relation of body position to readjustment on the basis of these two converse possibilities, we arranged two groups of experiments. In the first, A-2-a, we aimed to keep the conditions exactly as in A-1-a, the only difference being that glasses with lenses made of plain window glass were substituted for the prismatic spectacles. The reach to the right was about the same as in the earlier series since all four of the buzzers were set over to the right along the rod about 18 cm., that being about the average amount of linear distortion. A support for the rod prevented an exact shifting, the new positions being at 35, 48, 64, and 74 along the scale instead of at 53, 66, 79, and 92 as formerly. Instructions given the subjects were exactly the same, nothing being said about might be expected except in the case of one, A. M., who was given the suggestion that the glasses distorted the visual field and that she might be expected to adjust

to the left. Five subjects took the test—A. M., A. H. M., G., L. M. J., and E. S. R.

The results did indeed for all the five subjects show a curve. But the curve was very unlike that obtained for the preceding groups. It showed a rise, usually within the first three or four sittings, of between one and four cm., after which it settled down into a fluctuating "straight" line which rose at times only to descend again to practically the original level. The average curves for all four positions for 10 days are indicated in Figure X by the wavy line. It will be remarked at once that the curves are not much lower than for the first two groups in which the glasses were worn. But the significant thing is that while the curves for the first two groups keep on rising until half way up, those for this group continue to cling close to the lower line.

It is impossible to compare the groups in respect to remainders or per cents of readjustment, for in the group under consideration we have no individual linear deviations and no "normal" reactions as standards. But we *can* take as a measure the difference in centimeters between the highest point reached in 10 sittings for each buzzer, and the average of the five initial localizations for that buzzer. Taking the averages for groups A-1-a and A-2-a we get the results shown in Table II. (The numbers represent the four positions of the buzzers, from right to left, number four being at 92 for group A-1-a, and at 74 for group A-2-a.)

TABLE II

Amount of Improvement in 10 *sittings*

Group	Number of Subjects	1	2	3	4	Av.
A-1-a	7	7.9	6.7	6.4	5.8	6.7
A-2-a	5	4.3	3.3	3.3	3.3	3.5

It is seen that the average highest amount of increase over the first localizations is twice as much for the group wearing the prismatic glasses as for the present group. Only three of the five subjects in this group, unfortunately, continued the sittings beyond the tenth. Of these curves of G. shows an increase in amount of improvement of only 1.8 cm. in the last five sittings.

Subject E. S. R. continued for 26 sittings with no increase over the high point in his seventh sitting, but a slight and gradual decrease which brought his curves down at the end to within an average of a half centimeter of his record for the first sitting. (See curve Fig. IV, p. 38.)

At this point E. S. R. was started in the standard series, wearing the prismatic glasses. In 23 sittings he had gained 8.1 cm., an improvement of 41 per cent over the first standard sitting. Although his rate of improvement is slow, it seems clear that it is a readjustment to the new visual conditions. In Figure IV, p. 38 the unbroken line shows E.S.R.'s "progress" in the undistorted series, the distance from the lower dotted line representing average deviation in successive day's sittings from the actual position of the buzzer. Superimposed upon this curve is the broken line showing his progress while wearing the glasses (distorted series). Here the distance from the upper dotted line represents the actual position of the buzzer. This figure points clearly to an essential difference in the type of progress without and with glasses. In the former case there is wavering with no true upward progress; in the latter the curve, while it fluctuates, keeps on steadily rising.

In line with these results, though less conclusive, are those of A. H. Her curves *without* prismatic glasses do not for 15 sittings rise beyond the highest point reached in the first 10 sittings (an improvement of 3.8 cm.). But between the first and second sittings *with* prismatic glasses there is an average increase of 4 cm., pointing plainly to the operation of an effective incentive to readjustment.

It must be confessed that we have too few subjects in this "undistorted group" to justify an unqualified conclusion that without the prismatic glasses progress does not continue. More data are needed. But we can say that very probably the true situation is this: The difference in muscular strain caused by the unequal reach to the right, or the natural tendency to react with reference to the central body attitude, or both, do indeed result in a tendency to "readjust" to the left. This tendency, however, is very slight, and effective only for a short period. It could very well account for the rapid but brief initial rise which

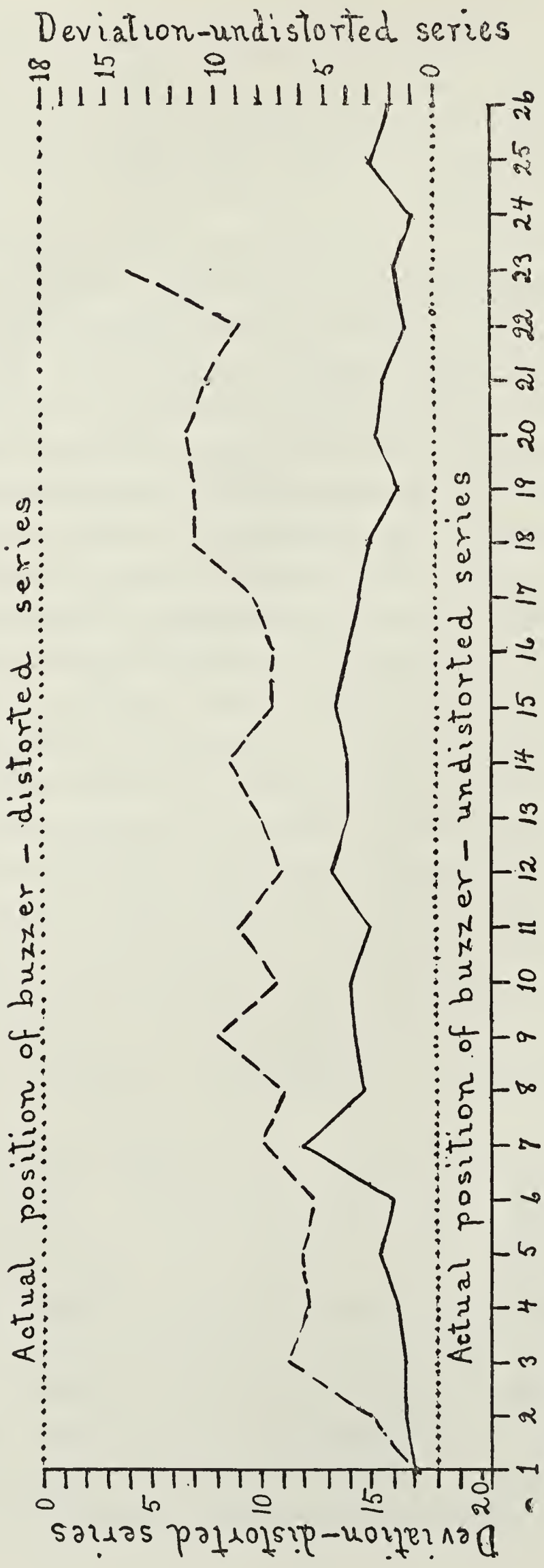

FIG. IV. Standard series. Undistorted and distorted vision. Subject E. S. R. Buzzer 1.

we noted as characteristic of the curves for the first two groups; but it could not account for the continued and steady progress of the curves which indicate a per cent of readjustment as high as 79. It would have been possible to devise an extra series to isolate the factors of muscular strain, due to long arm reach, and of head-body disparity; but owing to limited time this was not done. The two factors together did not prove, in fact, to have much influence, as will be brought out later.

b. *Experiments With Distorted Vision.*

In the second group of experiments to test the effect of the bodily attitude and muscular strain situations, our aim was to see if we could obtain a curve in the opposite direction, or at least one approximating a straight line, by shifting the buzzers far to the *left* as suggested, so that the localization of the buzzers *as distorted* would involve an unusual reach and a turning of the head to the left. Certainly if the first adjustment were independent of the prismatic glasses, such an adjustment could be produced in this way in a direction contrary to that which theoretically would take place to "overcome" the prismatic deviation.

In the new test, A-2-b, for three of the subjects all conditions were exactly as in A-1-b (Experiments without knowledge), except that the three buzzers were set far to the subject's left in such a position that when distorted, the one farthest to the right would appear to be, even for the maximum linear deviation, slightly to the left of the normal perpendicular to the central body axis, while the localization of the one farthest to the right would involve a long reach accompanied by unusual muscular strain. The positions on the scale for the three buzzers were 91, 101, and 117.

In Table III, p. 41, is a summary of the numerical results for this group. Fig. V, p. 40 shows typical curves, those of E. H. E. and R.

Four subjects took this test, all continuing for at least 10 sittings. Not one of them showed a tendency to readjust to the right. Three on the contrary showed a very marked readjustment to the left, working thus *against* an increasing sense of muscular

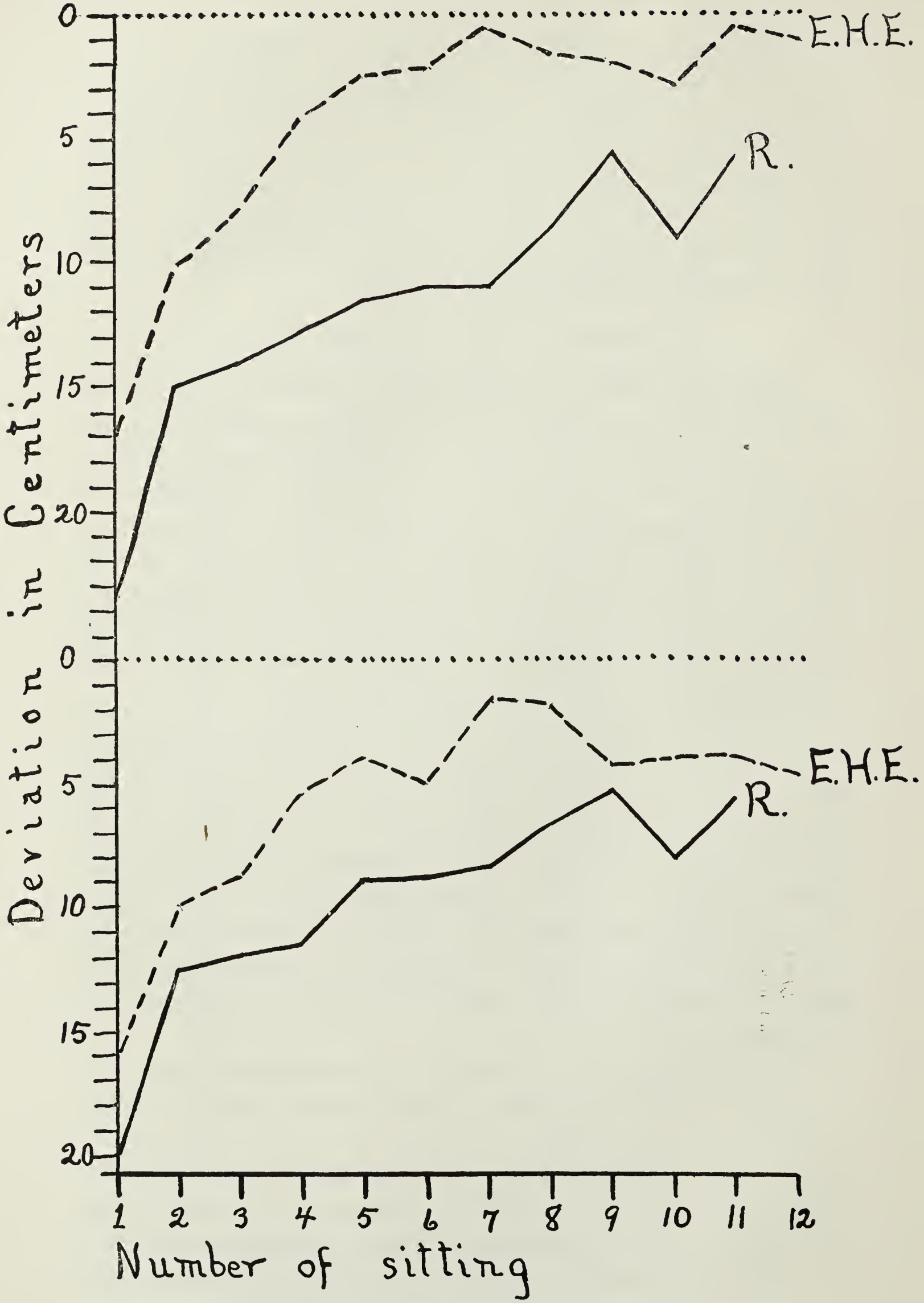

FIG. V. Standard series. Distorted.

strain, which they mentioned. The one who did not readjust remained more or less on a level for a few days, then fell to a level only very slightly higher than for the first sitting.

Of the three subjects who showed marked improvement, none were aware of the extent of the deviation and were even uncertain of its direction at times. E. H. E., on seeing her results, felt greatly surprised that she had been making a progressive change; and that the "feeling in her arms" did not inform her of this. She thought she had been hitting in the same positions all the time.

H. A. C. was very familiar with all the conditions of the experiment, and a highly trained observer. At the fifth sitting he reported that all the time he felt as if he were going too far to the left, and when his finger got there, he felt that if he moved it a little to the right, it would be more correct. At the ninth sitting he said, "Don't know whether I've improved or not—if I were going to guess, would say probably I hadn't—largely guess work."

In Table III is a summary of the results for the four subjects for a 10 day period.

TABLE III

Readjustment with Buzzers at the Left, Distorted Vision.

Subject	Average Remainder	Per Cent Readjustment	Average Initial L.D.
P. R.	5.0	68	15.5
F. O. D.	2.1	85	10.0
E. H. E.	.8	99	10.2
H. A. C.	10.0	22	9.8
Average	4.5	68	12.3

On first glance at these figures it would seem that the readjustment even on the average was so much more rapid than that in the standard series as to require the supposition either of another causative factor or of an unusual coincidence in the matter of individual variability. But consideration of the effect of the changed position of the buzzers explains this apparent discrepancy. The amount of linear deviation varies regularly with the size of the angle included between the line of fixation

and the line of projection (the scale), according to the formula $b = \frac{c \sin B}{\sin C}$ where b is the linear deviation (L. D.) and B the angle of deviation of the prisms. Now if the other angle, A, formed by the line of fixation for a buzzer and the scale is small, then the L. D. is correspondingly smaller. Now all the A's in this situation are less than right angles, while in the other groups all were greater. This means that the L. D. will be much smaller, and in fact we do find the average L. D. here, 12.3 cm., to be less than two thirds of the average L. D. for the first series A-1-a and A-1-b, which is 19 cm.

Now with a smaller L. D. the same absolute *amount* of readjustment would not only correspond to a disproportionately larger *per cent* of total readjustment, but the *remainder* would also be smaller. For example, suppose the absolute amount recovered by two subjects in each group to be 5 cm., and the L. D. to be 20 cm. Now for the subject in A-1-a this would represent 25 per cent of readjustment and a remainder of 15 cm., while for a subject recovering the same distance in group A-2-b, the per cent of readjustment would be 50 and the remainder only 5 cm. Hence we see that the two sets of results are not directly comparable, and may assume that in reality the average L. D. of these subjects would be about the same as in the first group, were conditions the same; and that the amount of readjustment would not be greatly different.

Now under the conditions of this series with distorted vision the head must be either in line with the body or turned farther to the left. Hence the fact that marked readjustment to the left nevertheless occurs proves conclusively that although the head-body discrepancy may have been, and presumably was, slightly effective in causing the original readjustment, a much more effective cause must have been at the basis of the readjustment for most subjects. The same statement holds for the hypothesis that the original readjustment may have been due to a gradual relaxation in attention to localization with a consequent following of the direction of least bodily effort, for in this case readjustment took place in the direction of increasing bodily strain.

It becomes necessary again to search for other possible factors. We have a gradual change in method of localizing, marked and steadily increasing for most subjects, without any known basis, sensory or ideational, for such a change. Now every reaction must have a conditioning stimulus, immediate or remote. What is the stimulus here?

After much pondering a possible solution of this problem came to mind, suggested by the line of reasoning followed in discussing the head-body position. Briefly the theory is as follows. The position of the eyes in the head is such that they are turned to the right of the head axis, just as the head is to the right with reference to the central axis of the body. It is the habitual tendency to react to the front as determined by head position rather than eye position which conditions the tendency to readjust to the left. The other factors of head-body position and of tendency to equalize strain may enter in as subordinate influences, but the main incentive to readjustment is the eye-head situation.

Let us see what the exact implications of this hypothesis are. It may be said that there are for the individual three distinct meanings of the word "front"—one with reference to the central axis of the body, one with reference to the head axis, and one with reference to the line of vision when the fovea is stimulated by the fixated object. Now it is reasonable to suppose the foveal front to be less dominating in the habitual reaction systems of the individual than the head front. In the first place the eye is much more active and varied in the direction of its fixation than the head. In the second place it is necessary to recognize the existence in this experiment of two different sensory aspects, visual and kinaesthetic, of the concept front, whereas normally the bodily reactions to the kinaesthetic and the visual situations are objectively the same. That is, the subject now *sees* the buzzer in front to be in one place, but with his head and body he *feels* that "front" is in another direction, farther to the left. If the subject wearing the glasses *saw* his head and body at the same time he *saw* the buzzer, it is possible that this old kinaesthetic set would be harmonized with the new visual situation and the localizations would be consistently in one place. But the glasses

are so constructed, and the conditions of the experiment are such, that the subject does not see any part of his head or body. Hence it is natural that the old or normal kinaesthetic reaction tendencies should be very strong when the subject is working under the injunction to reach out "in front", and that there should be a marked tendency to point in the direction of the head-axis rather than the eye-axis which is for the time being farther to the right.

At first when the subject might be expected to give particular attention to the localization of the novel visual object, he would respond to it by precise movements in harmony with the new visual situation. But since the attention of the subject gradually lessens and the process becomes automatic, it is quite natural that he should by degrees fall back into the more usual habit of reacting in harmony with the normal "feel" of the head. This would explain the gradual nature of the readjustment to the left.

The superiority of this explanation over the other hypotheses advanced lies in the fact that unlike them it works in the series with distorted vision just described. It is not hard to show that no matter what the direction of the line of vision, the eye will still be turned in its socket farther to the right than in normal fixation. In normal foveal fixation of an object the line of vision and the head-axis coincide. When the prism is placed before the eye of the subject, the object is deflected to the right, and in order to adjust properly to it the head is turned to the right together with the attached prism. But this turning of the prism again alters the angle of incidence of the ray of light from the object, with the result that it is refracted to the periphery of the retina. Hence and in order to obtain clear foveal fixation, the eye must turn still farther in the socket. Otherwise the object would be seen in peripheral vision, an unnatural situation for an object attended to. The amount of sequential turning of the eye is sufficient to make the eye-head discrepancy clearly apparent to the observer as the subject is in the act of localizing a buzzer.

This optical situation can be stated in a definite mathematical formula by the physicist, but it is sufficient for our purposes to recognize the mere fact that for every turn of the head there

will be a sequential turning of the eye still farther to the right, at an angle of noticeable extent, though less than the angle between the head-axis and the main body-axis. Taking into account the existence of this discrepancy, and the highly complex and delicate way in which the performance of any act is influenced by the total sensory situation at the moment, it is easy to understand the readjustment to the left as a perfectly natural adaptation to the changed sensory situation induced by the prisms. It is clear now why no marked readjustment occurs when the prisms are not worn.

The progressive character of the readjustment can be explained on this hypothesis in two ways. In the first place the subject might at first concentrate his attention on the visual stimulus and the correctness of his reaction to it, and hence react with reference to the "foveal front." Later, though the foveal fixation is still maintained, he might naturally relax his vigilance and fall comfortably into the more habitual manner of reacting with reference to the "head front".

Or, in the second place, he might continue consistently to react with respect to the foveal axis, but that axis itself might change, in, let us say, the following way. At first the subject, anxious to localize the object correctly, takes pains to get a clear foveal fixation. But this involves some muscular strain since the eye is turned farther in the socket than normally. And he *can* attend to the object visually through peripheral as well as foveal fixation. What is more natural than that, as the process of reacting becomes increasingly automatic, the eye should relax its tension and gradually assume a compromise position nearer its normal position in the head; or even continue until it has reached the normal position? This means that the eye-axis would slowly approach the head-axis, and finally, in some cases, coincide with it. Assuming that in this case the reaction of the subject is always with reference to the foveal front, the above assumption would account nicely for the progressive character of the readjustment to the left. Individual differences in readjustment would be due to physiological differences in susceptibility to muscular strain.

It seems probable that readjustment due to this prism-induced

eye-head discrepancy may be effected in both these ways, some subjects reacting in one way, some in another. That the general fact of the eye-head discrepancy is very significant for the process of readjustment appears highly probable. The chief merit of the hypothesis is that it will hold for the case in which readjustment to the left took place even in the direction of increasing bodily strain and in the face of a slight turning of the head to the left as compared with the body. For no matter what the direction of the object with reference to the body, we know that the eyes will always be turned in their sockets to the right of their normal position.

There are, however, some difficulties which indicate that this hypothesis is very likely only a partial explanation, and not sufficient to explain all the facts we have discovered in the course of our experiments. How, for instance, on this basis, can we account for the fact that in the case of R. D. in the Auditory Series readjustment occurred rapidly and surely, and then halted and remained on a level for ten days at exactly the point of objectively correct localization? R. D's localizations here were, moreover, far more accurate reactions than she had made to sound alone. According to the present theory why should the readjustment stop at any particular point, much less at this point? Unfortunately in none of the other cases in the first and second series where complete or nearly complete readjustment seemed to occur, were the sittings continued long enough to see if the process would go on indefinitely.

This hypothesis did not occur to the writer until after the conclusion of the experimental work for the investigation, when it was too late to check it up experimentally. In a later supplementary investigation, however, the writer hopes to carry out the experimentation necessary to clear up the matter.

It may be said parenthetically at this point that in the later series in which complete readjustment occurred, due to known sensory clues, the readjustment should on this theory go on, though at a slower rate, to a point some distance to the left of the actual position of the objects. There is no reason to assume that this would not have occurred, yet here again positive evi-

dence is needed, since the sittings were stopped when the actual position of the buzzers was reached.

VISUAL LOCALIZATION OF SOUNDING OBJECTS

1. First Group, Using Electric Buzzer

The second main series of experiments was designed to test the efficacy of sound as a factor in the formation of the new visual coördination. For the first group of experiments in this series one of the electric buzzers was used as the object to be localized. In this case it was sounded at each trial. One buzzer was used instead of four as in the preceding series, and shifted between trials to different ones of the four positions 53, 66, 79, and 92, according to a predetermined order. The object of using the one buzzer instead of four was first, to keep the quality of the sound as nearly constant as possible. It was found practically impossible to get four buzzers of the kind employed that were of the same pitch and timbre, or to equalize those we had. The second object was to make possible an easy identification of the sounding buzzer. If but one of four was sounding, it would be a hard task for a subject wearing the prisms to tell at once which one it was.

Before starting the main series of trials with distorted vision, a preliminary series was given to test the accuracy of the subject in normal auditory localization of the buzzer in the four positions. The subject, after being instructed how to reach out for the buzzer, was blindfolded and seated at the apparatus. At the signal "Ready," followed by the sound, he was to decide carefully at about what point along the rod the buzzer was, moving his head and body freely as desired, and taking all the time needed, the sound meanwhile continuing. When he had decided, he was to reach out and make the localization. When he touched the board the sound stopped. In order that the subject might not know or guess from what position the sound was to be expected, (1) he was not told that only four positions were used; (2) the trials were given in regular order but the order was frequently changed; and (3) the buzzer was moved noiselessly between trials, con-

versation going on in the meanwhile. The interval between trials was one minute. Fifty trials were taken for each of the four different positions of the buzzer, from 20 to 30 trials being given in a day's sitting.

When the preliminary series had been completed the subject began the series with distorted vision, with procedure exactly as in the first main series, A-1, except that the one buzzer, shifted between trials, was used instead of four, and that the experimenter gave the signal for reacting by sounding the buzzer instead of by placing her finger on it. The typewritten instructions were exactly as in the standard series, A-1, except for the change in describing the signal for reaction. Nothing was said about localizing the sound. The object was thus to see if the subject, while localizing the visual object, would be influenced by its sound, coming from a position to the left.

The results of this series as first given to four subjects seemed strongly to indicate that sound is efficacious as a factor in the formation of the new visual coördination. The progress of these subjects was noticeably more rapid than that of those in Series A, for in the 10 day period their average remainder was less by 24 per cent and the average remainder for *all* the sittings, or "total remainder," less by 41 per cent. While none of the subjects in the standard group showed a higher total per cent of readjustment than 75, and all but one fell below 60, only one subject of the four in the sound group (B-1) fell below 60, and one showed 100 per cent readjustment in 12 days. The sittings in both groups were continued until the apparent limit of improvement had been reached. Since on the average the individuals in the sound group had one less sitting than the standard group their smaller total remainder could not have been due to more practice.

In the course of these experiments with sound, certain of the subjects—and it happens the slowest ones—reported that they did not associate the sound with the buzzer at all. It seemed to come from another place, and so they got to thinking of it merely as a signal for reacting. One even persisted in believing, despite the assurances of the experimenter, that it was another

buzzer, behind the apparatus, that was sounding. This suggested the desirability of experiments to see if the fact of knowledge or lack of knowledge that sight and sound came from the same object, would make any difference in the rate of readjustment.

2. Second Group, Using Electric Bell

For this group it was necessary to use a sounding object in which the vibration at the time of sounding should be clearly visible to the subject. A "midget" electric door bell 3.5 cm. in diameter, mounted and made adjustable like the buzzers, and very similar to them in size and appearance, was used. The little hammer, painted a bright red, vibrated conspicuously when the bell was sounded. For the group in which the vibration was to be invisible, a small brass "wing" was made which could be quickly screwed to the upper part of the bell, and which effectively prevented the subject from seeing the vibrating hammer from any angle.

For these experiments with the bell the instructions to the subject were essentially as in B-1, except that for the group in which the vibration was visible the attention of the subject was called to the energetic tattoo which the little red hammer kept up when the bell was sounded.

Three subjects were used for the first group (B-2-a) in which the vibration was visible, and three for the second group (B-2-b) in which the vibration was invisible. The sittings were continued until the limit of improvement had apparently been reached—for this group, for about 30 sittings.

The results of the experiments with the bell were inconclusive. There was no appreciable difference in either rate or amount of readjustment. In fact the individuals in group b, who did *not* have the objective assurance that the sight and sound belonged together, showed on the average a slightly higher rate and amount of improvement than those in group a. Their average 10 day remainder was only 8 cm., while the corresponding remainder for the three in group a was 9.5 cm. The results of both groups were indeed strikingly like those for B-1.

After the experiments with the bell (B-2) two more subjects

were tested out for 10 days in the B-1 series with the buzzers. Both of these subjects (R. and H. E. C.) showed a very small amount of readjustment, their remainders for the 10-day period being 14 cm. and 12 cm. respectively, and the per cents of readjustment only 27 and 32. This brought the average in group B-1 so low that on comparing the two groups as a whole, we find a far less significant difference between the standard and the sound groups than had appeared before. The superiority of the sound group over the standard group was by these two additions reduced in regard to the 10-day remainder from 24 per cent to 14 per cent and in regard to the 10-day readjustment from 26 per cent to 18.5 per cent. It is a question whether the small per cent of improvement of these two subjects does not indicate merely a lack of general susceptibility to readjustment, an individual peculiarity that certainly exists. Unfortunately their sittings did not extend beyond the tenth, and so there is no way of telling whether, like O. B. B. in the standard group, they might have shown a spurt of progress later on.

The individual and group results for all 3 of the B groups are given in Table IV. The results for B-2-a (vibration visible) and B-2-b (vibration invisible) are combined after B-2-b, since there is no esesntial difference between them.

The figures for auditory accuracy reveal a good deal of individual consistency considering the relative crudeness of the arrangements. While there are wide limits of variability among the different members of the group, the average mean deviation for the group for all four positions being 6.3 cm., the individual variability is less. The highest mean deviation for any individual is 5.1 cm., while the lowest is 3.6 cm. The distance between the four different positions of the buzzers, it will be recalled, is 13 cm. All of the subjects, therefore, were able under normal conditions not only to distinguish by sound alone the four different positions, but within this range of 13 cm. quite accurately to localize the particular source of the sound.

Under the conditions of distorted vision the great majority of the subjects were conscious as soon as the sittings started of the approximate actual position of the sound. In general they re-

TABLE IV

Results for Three Auditory Groups.

Subjects	No. of Sittings	Visual Acc. 53	66	79	92	Auditory Accuracy 52	M. Dev.	66	M. Dev.	79	M. Dev.	92	M. Dev.	Av. M. Dev.	A.L.D. 1st 5 trials	Rem. 10 day	Rem. Total	Perct. Readj. 10 day	Perct. Readj. Total
B-1																			
F.D.	25	52.4	66.0	79.5	93.0	56	4.2	69.5	5.1	85.0	4.5	96.0	3.0	4.2	16.7	8.8	3.6	45	66
A.C.W.	19	55.0	68.7	82.0	94.0	68	3.6	80.0	3.4	86.0	3.0	94.0	3.4	3.6	18.9	12.6	6.4	33	66
R.D.	23	53.1	66.0	78.6	91.6	44	5.9	58.0	4.3	72.0	4.4	89.0	3.1	4.4	15.7	4.8	1.2	70	100
H.S.	13	52.8	67.2	79.8	92.3	45	4.6	53.0	5.5	63.0	4.9	75.0	5.4	5.1	22.2	12.9	11.5	42	49
R.	11	54.1	66.9	79.5	91.9	53	3.7	69.0	4.6	81.0	4.0	93.0	4.3	4.4	19.4	14.2	14.2	27	..
H.E.C.	11	55.9	68.3	79.9	92.5	58	..	68.5	..	79.0	..	90.4	..	..	17.1	11.6	11.6	32	..
Average	20					54	4.4	66.0	4.6	77.7	4.5	90.0	3.8	4.3	18.3	10.8	7.7	41.5	73
B-2-a *Visible*																			
H.K.	11	54.6	67.4	82.7	91.8	..	..	...	..	...	..	...	..	..	18.6	14.3	14.3	23	..
C.W.L.	45	55.4	66.4	80.4	92.3	..	..	...	..	...	..	...	..	..	21.7	7.9	4.2	64	81
M.M.	40	50.6	65.1	77.8	91.3	..	..	...	..	...	..	...	..	..	22.6	10.3	3.6	55	88
Average	32														21.0	10.8	3.9	59	84
B-2-b *Invisible*																			
K.E.L.	31	53.1	66.8	79.8	92.4	..	..	...	..	...	..	...	..	..	21.4	5.2	3.8	76	82
F.L.B.	25	54.5	68.2	80.0	94.5	..	..	...	..	...	..	...	..	..	15.3	3.3	1.3	79	91
C.S.	25	54.1	65.6	79.7	91.6	..	..	...	..	...	..	...	..	..	15.4	7.4	.2	52	99
Average	27														17.5	5.3	1.8	69	91.0
Av. B2	29.5														19.6	8.0	2.8	64	87.5

ported that it seemed at each trial to be to the left of the buzzer, estimating the distance to be from 6 to 30 cm. from its apparent position. Subject C. S., in group B-2, is the only one who thought for a while that the sound was to the right, but she soon discovered her error.[1] Subject M. M. (group B-2) is the only one in the series (including 15 subjects) who did not at any point in her sittings localize the sound as to the left of the apparent position of the object.

In considering the remainders and per cents of readjustment in the sound series it will be convenient to deal with the group results. In Table V, p. 58, is a summary of the results by groups of A-1, the standard group of seven subjects, using four buzzers; B-1, the first sound group of six subjects, using one buzzer; and B-2, the second sound group of 6 subjects, using the bell. The

TABLE V

Summary of Group Results for Series A and B

Group	No. Subj.	Av. L.D.	R. 10-da.	R. Total	Sittings	Per cent Readj. 10 da.	Per cent Readj. Total
A-1-a	7	19.1	12.5	8.7	21	35	56
A-1-b	4	17.7	10.6	9.1	22	38	(47)
B-1	6	18.3	10.8	7.7	22	41.5	(73)
Improvement of B-1 over A-1			13.6%	11.5%	1	18.5	(30.3)*
B-2	6	19.6	8.0	2.8	29.5	64.0	87.5
A (1-a and 1-b)	11	18.4	11.5	8.9	22.0	36.5	(47)*
B (1 and 2)	12	19	9.4	5.3	25.7	52.7	80
Improvement of B over A			17.2%	40%		44%	(70%)*

* For four subjects only.

[1] Toward the beginning of her sittings, C. S. even reported at one time that she "saw the experimenter in one place and heard her voice in another" (to the left). It is of interest here to note that M. O. W. (in series A-2) first discovered the direction of the prismatic deviation through noticing a similar discrepancy between the sound of the experimenter's voice, and her position as reported by sight.

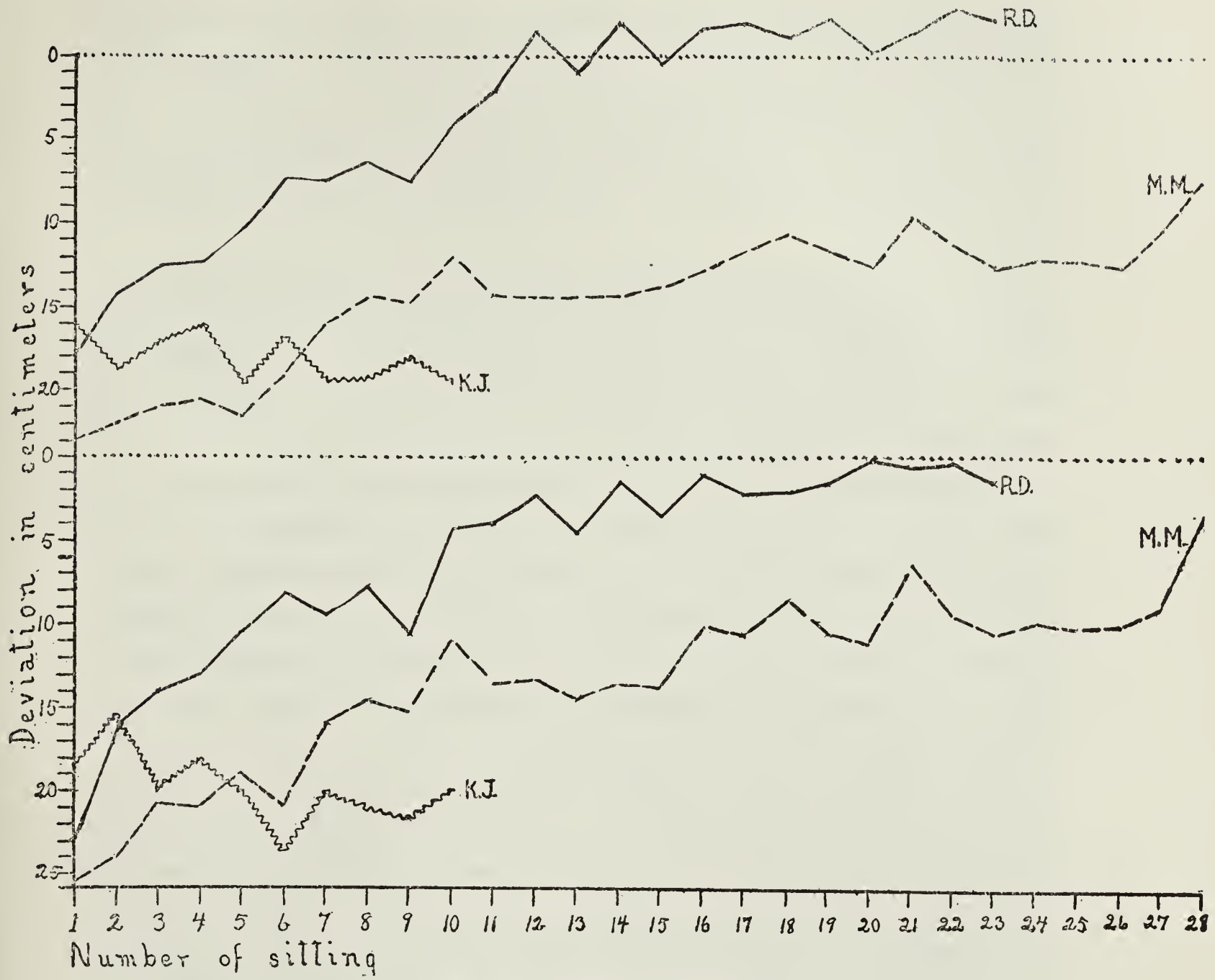

FIG. VI. Auditory Series.

combined results of B-1 and B-2 and the combined results of A-1-a and A-1-b (without knowledge) are also given.

The group curves for A-1 are shown compared with the group curves for B-1 in Fig. X. Specimen curves for B are given in Fig. VI.

From an inspection of these tables and curves it will be seen that there are some indications that sound is an influential factor in the process of readjustment. Comparing group B-1 with the standard group in which the buzzers were not sounding, we find for the 10 day period a remainder less by 13.6 per cent than that for the standard group, and a per cent of improvement 18.5 per cent greater. If we combine the results for A-1 (with knowl-

edge) and A-2 (without knowledge), and compare them with the combined results for B-1 (using buzzer) and B-2 (using bell), we find a still greater difference. The 10 day remainder for the sound group is now less than that for the standard group by 17.2 per cent. The amount of readjustment for 10 days is greater by 44 per cent.

Now while these differences, considering the large amount of individual variation, by no means justify even the positive conclusion that the sound had any influence at all in forming the new coördination, they certainly do indicate the probability that sound may be a factor.

An indication that sound as employed in our experiments may be a factor in the formation of the new coördination, is the fact that some subjects report that they feel a positive "pull" in the direction of the sound, or in other words, toward the actual position of the buzzer. A. C. W., for instance, in his later sittings, felt such a tendency. Localizing the buzzer as it appeared to be, he described as like "pushing up stream."

This consideration is offset by the fact that a majority of the subjects not only felt no "pull", but paid very little if any attention to the sound. The report was common that the sound served merely as a signal for reacting, or as a sort of "orchestral accompaniment". Several, though they always localized the sound —as to the left—felt that it made no difference in their reactions. The most striking negative evidence occurs in the case of M. M. (group B-2) who, though she made steady progress and finally made a readjustment of 88 per cent, reported that she was not at all conscious that the sound was to one side of the buzzer, and did not even know until the very last the direction of the distortion. (See M. M's curves in Fig. VI.).

One subject, K. J., localized the sound as to the left, and mentioned noticing it frequently. It was impossible to get him to adopt a naive attitude toward the experiment, and it was quite evident that he was determined to resist the suggestion that occurred to him that the sound was expected to influence him, as these typical remarks indicate: "Of course you realize the sound doesn't make a particle of difference," and "Why are you

sounding the buzzer at all?" In K. J's curves given in Fig. VI we see an actual progressive regression from the actual position of the buzzer, a unique situation among the 72 subjects. It seems plausible that the regression may be due to the unconscious influence on the localizations of the stubborn determination not to be influenced by the sound.

As a matter of fact, suggestive as the above reports of subjects are as to the factors which did or did not influence them, they have not a particle of value as scientific evidence. A subject might be sure, as M. R. G. was in series A, that he was reaching to the same point each time, and yet actually be steadily advancing to the left, influenced by factors of whose existence he was entirely unaware. Similarly, subjects who reported that they paid no attention to the sound may nevertheless have been influenced by it, just as people may respond to irritating stimuli during sleep, or waken if an accustomed stimulus ceases.

An attempt to see whether the sound might cause additional readjustment after a subject had reached the limit of improvement in the standard series, proved fruitless as far as gaining definite evidence was concerned. This is what might have been expected, for as has been pointed out, it had been found that some subjects in the standard series whose curves remained on a level for some time, showed unexpectedly new progress in readjustment. The fact, however, that four out of the five subjects tested in this way did show at least a slight improvement immediately after the introduction of sound, is worthy of attention. The subject whose curves exhibited no change whatever on the introduction of sound was M. W., the writer, who was, it happens, the only one in the standard series who showed no progress in that series. The improvement shown by M. R. G. and D. S. is only what might have been expected had no change in conditions been made.

In series A-2, however, the increase in readjustment of M. O. W. and of M. Mc F., after the introduction of sound, seems possibly significant. The curves of M. O. W., which after 28 sittings had remained on a level for six sittings, showed an average rise of 2.5 cm. in the first sitting in which sound was given. In

the next 16 sittings the per cent of readjustment increased from 37 to 45. The curves of M. McF., which after 35 sittings had remained at a level for 10 days, showed a slight rise during the three days after the introduction of sound (an average rise of 3.4 cm.). There was then a slump due to a fortnight's vacation and a 10 days' absence on account of illness, after which the curves showed a steady rise for nine days and a total advance over the record for the sittings without sound, of 34 per cent in amount of readjustment, while the remainder decreased from 8.6 cm. to 4.2 cm.

Such facts as the above may well make us hesitate before concluding that sound has no efficacy in our experiments. Another aspect of the situation is this: Inasmuch as subjects in the standard series have shown a great deal of individual difference in susceptibility to whatever factors make for improvement, may it not be that some subjects are influenced by the sound and others not? May not the unusually rapid progress of R. D. and of C. S. be correlated with their interest in the sound and its location, while others are not similarly influenced? Here of course the influence of sound, if there be any, may be said to consist merely in the emphasis of the direction and amount of distortion. The situation is so complex, and there are so many possible factors that it is in fact impossible to conclude from the slight evidence we have, that sound is efficacious in these two cases.

Even if sound does have some influence in the process of readjustment, it is clear that in our experiment, that influence is slight, and not susceptible of quantitative measurement. As an illustration let us take the case of R. D., who showed a readjustment of 100 per cent in 12 sittings. From an inspection of her curves in Fig. VI, it is seen that for 10 days after attaining an approximately correct localization of the buzzers, the curves fluctuate about the same general level. Now if it were the sound of the buzzers that was determining her localizations, the average for these 10 sittings should roughly coincide with her average normal auditory localization. But as a matter of fact R. D. localized the sound of the buzzer normally over 6 cm. to the right of its actual position. (See Table IV.) While the sound may have influ-

enced her, then, it was not by virtue of exerting a definitely measurable "pull" toward a certain particular position.

In this connection it is pertinent to note the fact that while the exact localization of the sound is unstable and shifts within rather wide limits, it is for the great majority of the subjects at first a relatively independent matter. At the begining of the sittings the sound is clearly assigned to a position definitely to the left of the object as seen. It is only as the sittings progressed and readjustment took place that the discrepancy between sound and sight was reported as becoming less. Many of the subjects reported that at the close of the sittings sight and sound seemed to be at last together, and the finger to "feel" in the right place too.

Now while the sound comes finally in the process of readjustment to be "pulled over" to the sight, the subjects were not so suggestible on this point as some of Stratton's observations might lead one to expect. The localization of the sound in our experiments is a relatively independent matter, changing only gradually in response to the demands of the practical situation.

The following conclusions may be drawn from the experiments on sound in series B:

1. There is evidence that sound may have a slight influence in the formation of the new spatial coördination developed under the conditions of our experiment, especially for some subjects.

2. If sound does have an influence, this influence operates in general without awareness of that fact on the part of the subject.

3. The fact of perceiving or not perceiving the direct connection of the sound with the vibrating visual object, has under the conditions of our experiment no influence on the rate or amount of readjustment.

4. The conditions of our experiment are not definite enough, especially in the matter of directions to subjects, to insure a fair test of the efficacy of sound as a factor in the formation of the new coördination. There is need for a better experimental technique in this matter.

LOCALIZATION WITH TOUCH

The next series, C, was designed to determine the influence of contact with the buzzer upon the rate and amount of readjustment to the changed visual conditions. For this series one buzzer only was used. This was shifted from one of the four positions to another according to a regular order. The slit at the back of the cover was widened just enough to permit of lowering the buzzer half way down through it. The subject, on making a correct localization, would thus touch the lower half of the buzzer without seeing his finger. The contact with the relatively cool smooth buzzer was distinctly different in quality from the usual contact with the wood forming the back of the apparatus.

Contact was the sole means of determining the actual position of the buzzer. It was not sounded. The localizing finger could not be seen by the subject even though the slit was wider than in the preceding series, because the narrow wood strip one cm. in thickness (which formed the front of the frame supporting the sliding cover) acted as a sort of screen. As in the preceding series, in order that the subject might not find out the extent of his error by visual means, through seeing the experimenter's movements in getting the records, the black curtain was drawn after each localization.

1. Passive Touch, as the Result of Chance Success

In the first group of experiments with touch the subject localized the buzzer exactly as in the standard series, reacting to its apparent position, but with the knowledge that when he made an objectively correct localization he would touch the buzzer. In other words he knew each time he reached out that he was missing the buzzer. There would be no actual contact with the buzzer, then, unless by accident or until almost complete readjustment should occur.

In the case of the three subjects in this group, it was found that the knowledge each time that the localization was wrong, had apparently no effect upon the rate of readjustment. The results were in all respects like those of the standard series. (See

Table VI.) Complete readjustment occurred in the case of only one subject. In his case it was plainly due to an accidental direct con-

TABLE VI

Groups C-1 (Active Touch) and C-2 (Passive Touch)

Subjects	No. of Sittings	Visual Acc. 53	66	79	92	Av.L.D. 1st trial	Rem. 10 da.	Rem. Total	Per Cent Readj. 10 da.
C-1									
T. L. W.	18	53.5	66.5	80.6	93.7	13.	+1.4	+1.4	90.
M. K.	10	53.9	65.8	78.3	91.0	21	18	..	14
R. J. B.	20	54.1	66.8	78.6	91.2	22.3	19.3	19.3	13
C-2									
F. D.	11	53.4	67.0	79.9	92.4	24.9	.5	..	98
D. B.	13	55.0	67.6	81.0	94.0	23.4	3.4	2.0	85
M. B.	10	53.0	66.0	79.7	91.9	19.1	.23	..	99
G. B.	12	52.8	66.8	79.3	93.0	20.4	1.0	.55	95
F.	10	53.9	66.6	80.0	92.2	21.2	.96	..	95
Average	11						1.02		94.4
R. D.	9	53.2	66.0	78.3	91.7	8.4	10.2	..	45

tact with the buzzer. The other two did not approach sufficiently close to the buzzer to admit of the occurrence of a chance touch. One of these subjects, R. J. B., was one of the few of the entire number of 72 subjects who, like M. W. in the standard series, made no significant progress at all, although she had 20 sittings. The results for this group, then, were indeed essentially like those of A-1, and served only still further to confirm the conclusions drawn from them.

The results of one subject of the three, however, furnish a bit of interesting evidence. T. L. W. *accidentally* touched buzzer four, at position 79, at the first localization in his fifth sitting. As a result all the following localizations were much nearer the actual position of the buzzer, although T. L. W. *was not conscious of the change*. (See T. L. W.'s curves in Fig. VII.) The curves for all the positions, which had for the four sittings shown no advance at all, rose after this *one* contact experience an average of 6. 1 cm. in the one sitting! Moreover, the influence of the contact was strongest for the particular position where it occurred, (buzzer 3) and least for one farthest away (buzzer 1). At the end of the 10th sitting there was complete recovery for buzzer 3, but

for buzzer 1 recovery was not complete until the 18th sitting. All this regular and rapid readjustment took place while T. L. W. was reacting automatically to the position of the buzzer *as it appeared to him!*

The case of T. L. W. shows in a striking way the marked efficacy of direct contact as a factor in readjustment. But it is plain that with the instructions used in this group, direct contact would occur only rarely, in the case of a few subjects.

The results of the group as a whole show only that the objective knowledge of error, when contact was not felt, had no effect in hastening readjustment. This is significantly in line with the results of Series A-1-b (without knowledge).

2. Active Touch, as a Check at Each Localization

In the next series the aim was to test the influence of the factor of active touch as a check at each localization. For this group the subject reacted, as in all the series, to the *apparent* position of the buzzer. But after each localization made in that manner, he checked the accuracy of his localization by actual contact, according to the following directions:

"When you have touched the board, keep your finger in position while the screen is adjusted and until the experimenter says 'All right.' Then, not taking the finger from the board, move it along until you touch the side of the buzzer. Then put your finger tip squarely on the black line as it extends beneath the cover. Now sit back in the chair and wait for the next 'Ready' signal."

After the first localization the subject would move his finger uncertainly along the board, as often in the wrong direction as the right one, and would usually not touch the buzzer until after some retracing. After this there would be, *after* each localization, one natural movement in the right direction, leading to the contact experience. Of course with this revised procedure we do not have as the additional factor a simple contact value, but one complicated with kinaesthetic stimuli. In other words we have active or exploratory, rather than passive touch.

In dealing with the results of series C, D, and E we must keep in mind the fact that in these groups, as pointed out in the dis-

cussion on pp. 18 and 19, the per cent of readjustment is a less reliable measure of improvement than in series A and B. This, it will be remembered, is due to the fact that in these later series the readjustment occurs so rapidly as to make extremely ambiguous the figures expressing initial linear deviation.

An illustration from series C-2 of the fact that readjustment takes place within the first four trials is afforded by the results of D. B. From Table VI, p. 64, it is seen that her initial deviations for positions 53, 66, 79, and 92 are 24, 23.1, 27, and 19.5 cm., respectively. Now according to the linear deviation calculable from trigonometric formula on the basis of the angle of the prisms and the angle at each of these positions,[1] the greatest deviation should be at 53, and the amounts should be successively less for the other buzzers. The fact that instead the order of greatest deviation is 79, 53, 66, and 92, is easily accounted for by the fact that the trials were given in just that order. Thus for each successive trial we have a decrease in deviation, due to the tendency to readjustment—a decrease so marked as to obscure the common objective difference in linear deviations due to angle and position.

The individual results for series C are given in Table VI, and specimen curves in Fig. VII. In the table a plus sign before a remainder indicates that it represents "over-correction", or localization to the *left* of the actual position of the buzzer. The curves for four of the five subjects in group C-2 exhibit a uniform and gradual, but very rapid readjustment. On the average the remainder of these subjects at the end of the 10th sitting is only 1.02 cm., and the per cent of readjustment is 94.4. One subject, R. Dixon, is a notable exception. Apparently touch is not effective in her case at all, for her very lowest remainder is 10.2 cm., and after that point (at the sixth sitting) her curves recede again until at the ninth sitting they are nearly as low as at the beginning.

These results are decisive evidence that touch is a powerful factor in the formation of the new habit of spatial reaction. That one subject was apparently not influenced by this factor, only indicates again the existence of marked individual differences in

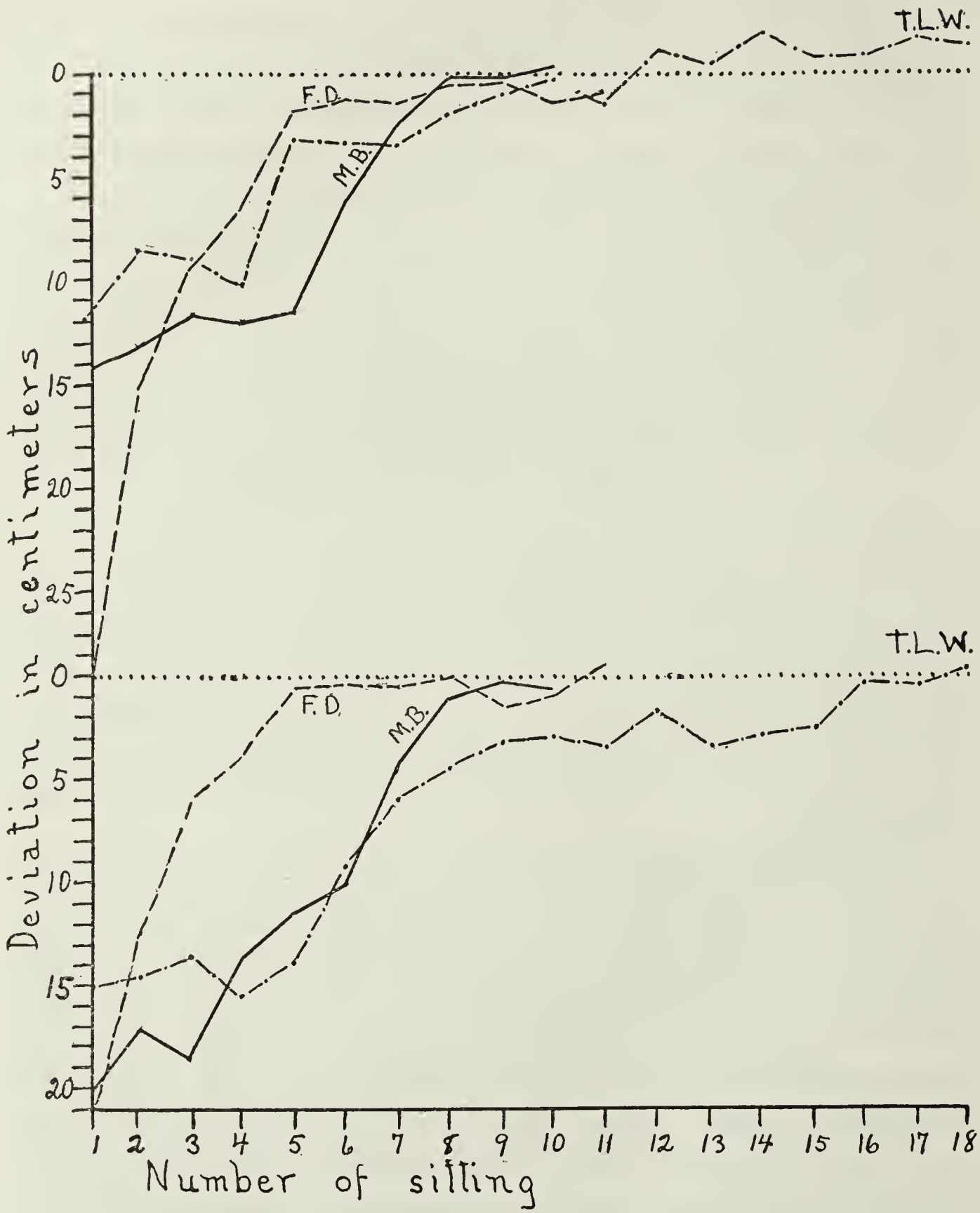

FIG. VII. Tactual Series.

$$^{1}\,b = \frac{c \sin B}{\sin C}.$$ See p. 42.

the matter of adjustment to spatial relations. The gradual slope of the curves, the striking correspondence for each subject of the curves for the four different positions, and the general similarity of the curves of the five subjects who did readjust, all

point to the operation of a consistently powerful stimulus to readjustment.

The fact that the readjustment did not occur on a conscious level needs to be emphasized here. At each trial the subject reached out naturally and automatically toward the buzzer *as it appeared to him.* There was, after each localization, the knowledge that the actual object had been missed, and the awareness through previous tactual-kinaesthetic experience of its approximate location. But since there was no conscious attempt to correct, the "re-harmonization" evidently took place in response to a need for a practically effective response, of which the subject himself was not clearly aware.

LOCALIZATION WITH VISUAL PERCEPTION OF AMOUNT OF DISTORTION

The aim of series D was to determine the relative influence of sight of the localizing finger after the response, in the formation of the new spatial coördination. For this series the slit at the back of the cover was made wide enough to permit the introduction of the finger tip when a localization was made, in such a way that the tip only of his finger was visible to the subject. At the same time the buzzers were raised to such a height that the finger tip, when appearing just beneath the black line, did not come in contact with the buzzer. All four buzzers were used. Instructions and general procedure were exactly as in the standard series. Thus by having the subject react to the apparent visual position of the buzzer, we were able to test the effect of visual perception of the amount and direction of error.

Ten subjects took part in this series. The results are given in Table VII, p. 67, and Fig. VIII. The results of E. B., M. L. P., P. and P. I., while given in the table, are not included in the general averages for the group. This is because they had less than 10 sittings and did not quite reach complete readjustment. In this table, as in Table VI, a plus sign before a remainder indicates an excess of localization to the left.

It was perhaps more difficult in this group to maintain a per-

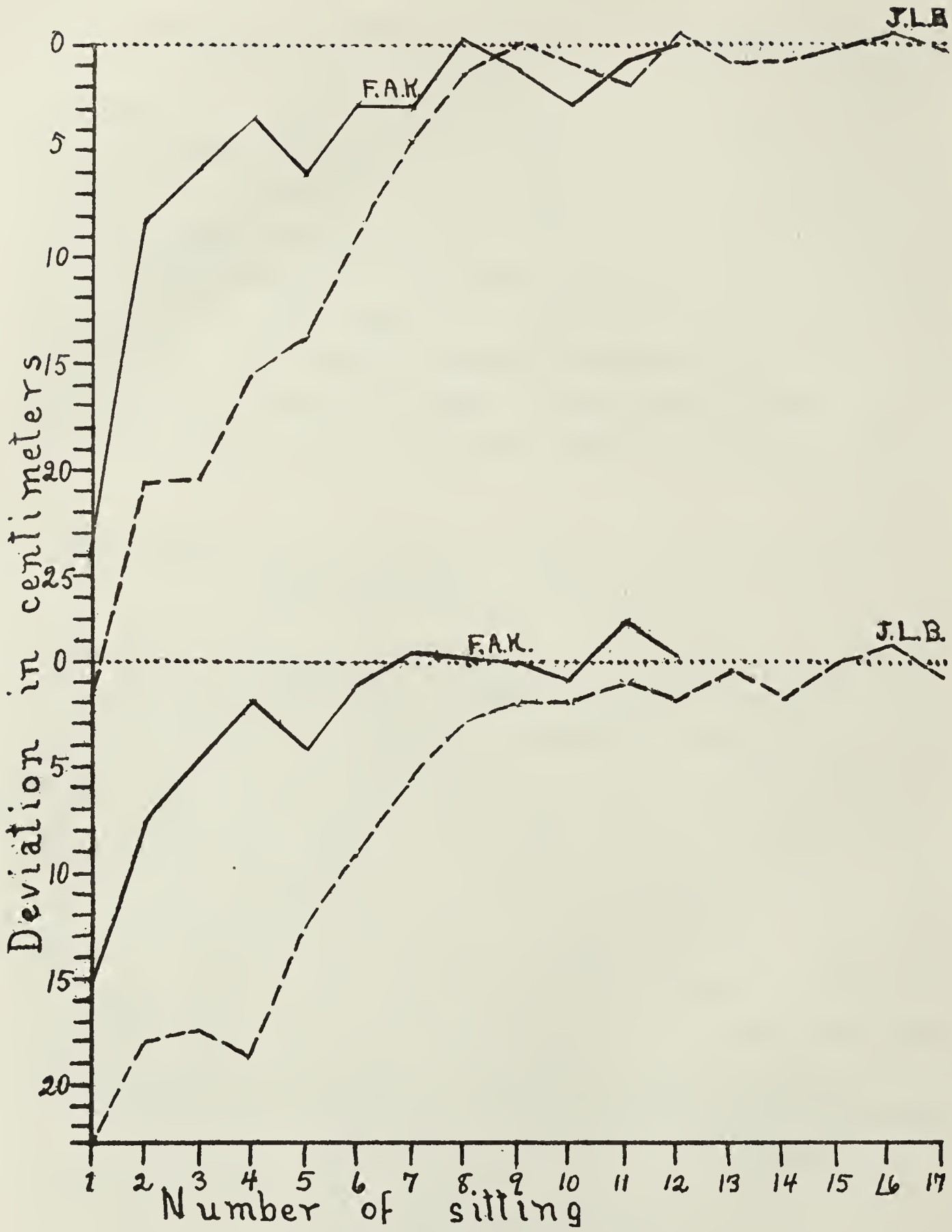

FIG. VIII. VISUAL GROUP.

fectly naive and uncritical manner of response, with no conscious effort to correct, than in any other series. But there were more subjects, and more highly trained subjects, in this group than in any other group. They all reported that the process of readjustment was purely effortless and they were uniformly surprised when the distance from the buzzer first began to decrease. That

the process was spontaneous and automatic is indicated by the strikingly gradual slopes of the curves and their uniformity for the four different positions.

The curves of all 10 of the subjects in this group show a very rapid readjustment, amounting in 10 sittings to an average per cent of readjustment of 97, with a remainder of only .4 cm. This shows that in our experiment, vision and touch seem to be almost equally powerful factors in effecting a readjustment to the new spatial conditions. The curves for the groups (C and D) in Fig. X exhibit about the same general height and slope.

A study of both the curves and tables, however, reveals significant differences. In the first place the group curves seem to indicate that the *rate* of readjustment is more rapid for series D than for series C. The curves for the sight series, D, are consistently higher on the average than those for the touch series, C. Especially striking is the difference for the first two sittings. On first thought this would seem to indicate a more rapid initial readjustment for sight than for touch. The numerical results in Table IX, p. 73, however, suggest that this may not be really the case, and that the average amount of deviation is so much less in the case of sight, not because there was a good deal more progress within the first sitting, but because the average *initial* deviation for the group was less by 4.5 cm.

But why is the average initial deviation so much less than in the case of the sight series? There are two possible reasons. First, it may be due to mere individual variability and the lack of a sufficient number of cases to strike a typical average. There are only ten subjects in Group D and seven in Group C. Second, it may be due to so rapid a readjustment in the case of the sight series that the average deviation for the four buzzers combined may be significantly less than the deviation for the first buzzer localized in the sitting, which was in this group buzzer 92.

Now as a matter of fact the second explanation proves on analysis of the results to be the true one. While the average deviation for all four buzzers is 17.6 cm. for the sight series, the deviation for buzzer 92 is 21.3 cm. for the group, a difference

of 3.7 cm. Had the first buzzer to be localized by the group been 53 or 66, this deviation would have been still greater, owing to the fact that the standard objective deviation for buzzer 92 is the least of the four buzzers. The average *initial* deviation for the other three buzzers is markedly less than for buzzer 92, because the process of readjustment set under way by the first localization of buzzer 92 is already proceeding rapidly.

Taking these facts into consideration it is clear that the average deviation for series D, which is calculated on the basis of the average of the initial trials only for each position, is smaller than that for series C for the reason that there is indeed a very rapid readjustment within the first four localizations in the first sitting. Individual variability might account for a small amount of difference in the average initial localizations for the two groups, but it could not possibly in itself account for the striking difference we actually find.

The second significant difference between the results for the sight and the touch series is found in the fact that not only is the rate of readjustment for the former greater, but the absolute amount of readjustment effected within the given 10 day period is greater. The average remainder for the visual group is only .4 cm., as contrasted with 1.02 cm. for the tactual group. (Table IX.) In the visual group four out of the seven subjects who took 10 sittings showed a complete readjustment, while not one of the seven subjects in the tactual group effected a *complete* readjustment. Another indication that the influence toward readjustment afforded by the sight of the discrepancy was more strongly operative than the tactual factor, is the circumstance that in the visual group five out of seven subjects show a small average "over correction" (.15cm.) while no individual in the tactual group showed an average "over correction" for the four positions. It is as if, having felt a strong impetus toward readjustment, the subjects in the visual group were carried a little way past the goal by the mere force of inertia.

We had the opportunity to find out whether sight was a more powerful factor than touch in the case of one individual, owing to the fact that after a long series of sittings with touch (19)

she showed absolutely no further improvement. The factor of sight was then substituted for that of touch with the result that an immediate improvement set in, and after 13 sittings the subject (M. W., the writer) had made a complete readjustment.

A comparative study of the results for series C and D, then, indicates that the factor of sight as used in our experiments is more efficacious in the formation of the new coördination than the factor of touch.

TABLE VII

Visual Perception of Amount of Distortion

Subjects	No. of Sittings	Visual Acc. 53	66	79	92	Av.L.D. 1st trial	Av.Rem. 10 days	Total Per Cent Readjust.
J. L. B.	17	53.3	66.0	78.9	92.2	20.4	1.4	93
P. J. R.	10	53.8	66.1	78.7	91.6	16.0	2.3	86
G.	10	53.0	66.3	79.0	92.0	20.0	.2	100
A. D. U.	12	52.7	66.5	98.8	91.3	15.2	.2	99
D. H. B.	6	53.6	66.2	79.3	91.8	14.5	.15	101
F. A. K.	11	52.7	66.3	79.	91.2	17.3	.1	100.1
F. R.	8	52.5	66.9	78.8	91.5	19.8	.1	100
Average	10.6					17.6	.4	97
E. B.	7	53.4	64.6	78.1	91.9	18.7	.5	97
M. L. P.	6	53.5	65.0	78.2	93.5	16.2	.4	97
P. I.	7	53.1	65.2	78.6	92.3	13.4	1.1	92

LOCALIZATION WITH TACTUAL-KINAESTHETIC CLUES FROM LEFT ARM

Perhaps one of the strongest habitual simple space coördinations employed in daily life is the coördination between right and left hand and arm movements, so necessary for grasping and handling objects. Were some form of this coördination broken up by the wearing of the prismatic glasses, it would seem that there would be an unusually strong tendency to re-form the coördination under the changed visual conditions. It was the aim of series E to see what is the relative strength of this tactual-kinaesthetic influence toward readjustment as compared with the other factors investigated.

The procedure was as follows. The subject was seated at the apparatus in the usual position, wearing the glasses. While his eyes were closed his left arm was extended out *over* the cover by

the experimenter, and he was directed to bend the left index finger so that it would extend downward at the back of the apparatus through the slit, which had been sufficiently widened for this purpose. When his finger was in position the subject was permitted to open his eyes. He was then directed to localize his left index finger as in the normal series, by a direct movement of the right index finger to the part of the left finger extending beneath the cover. He was, as in the other series, to localize the finger as it was visually perceived, disregarding the fact of distortion. The experiment thus tested the influence upon localization of clues as to the correct position of the finger derived through the tactual and kinaesthetic senses.

The slit was so wide in this series that in order to prevent sight of the localizing finger by the subject it was necessary to provide a movable cardboard strip to cover the movements of the finger. In the middle of this strip, which is 56 cm. long and 8 cm. wide, is an aperture shaped like a half moon through which the left finger of the subject was extended. At each trial this opening was set at the desired position, 53, 66, 79, or 92, as the case might be. The same order and number of trials and the same length of interval were maintained as in the other series.

With this manner of procedure the subject was kept just as much in ignorance of the direction and amount of the distortion as in the standard series. The only difference was that in this series tactual-kinaesthetic sensations from the left arm afforded clues to the actual position of the object. Had the subject been permitted himself to extend his left arm over the cover and his finger down through the aperture, he would have gained not only knowledge of the nature of the distortion but practice in overcoming it. It was for this reason that the experimenter put the arm of the subject in place herself, and was very careful that the subject should withdraw it while his eyes were closed and the curtain still in place in front of the line of localization.

Six subjects served in series E, for 10 days each. Results are given in Table VIII, p. 71 and Fig. IX p. 69. The most striking feature of the data is the fact that for all of the subjects the

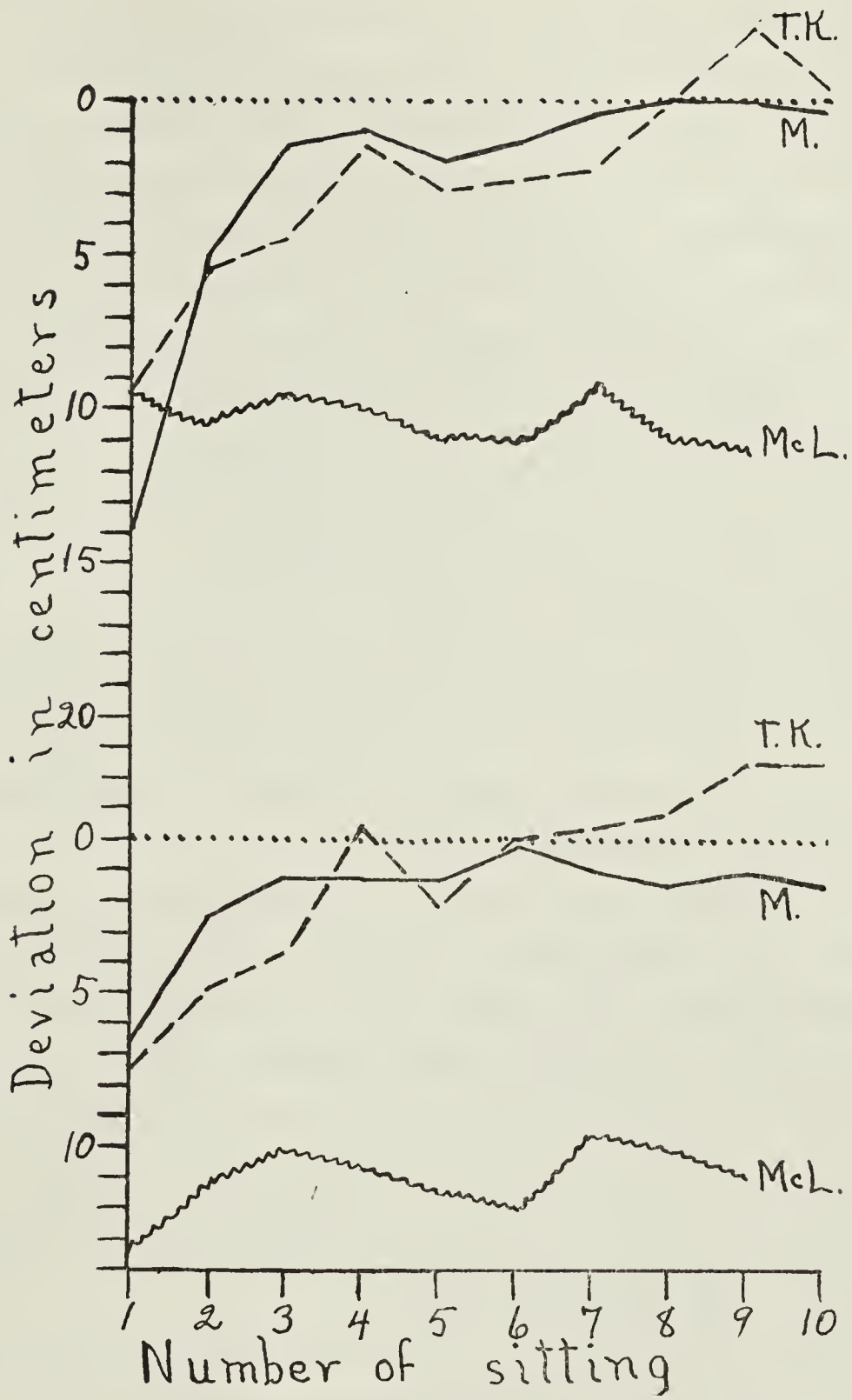

FIG. IX. Tactual-kinaesthetic Series.

initial linear deviations are very much lower than in any of the other series. The average linear deviation for this group is only 9.5 cm., while the lowest average for the four other series, that of series D, is 17.6 cm. The average even for the first position localized, 92, or buzzer 4, is only 10.3 cm. This fact can apparently mean only one thing, viz., that the tendency to effect a practical coördination of the movements of the two hands is so strong that it is impossible with our glasses to break it up, although the sub-

jects acted in innocent and even ignorant good faith in trying accurately to localize the left finger *as it visually appeared to them.* In other words, "readjustment" to the changed visual conditions is on the average more than 50 per cent effective prior to the first localization. Moreover, since the subjects reported that they were unaware of the direction of the distortion, this "readjustment" was unconscious on their part and occurred solely on the basis of the retention of habitual kinaesthetic attitudes.

In the tactual-kinaesthetic series, it is to be kept in mind that the influence of the sensory incentive to readjustment was operative before the first localization. In the auditory series a similar situation prevailed, since the sound afforded a clue as to the actual position of the buzzer before the first trial was made. In the sound series, however, the influence of such a condition was not apparent, while in the tactual-kinaesthetic series it was very marked. In no other series could the clues be perceived before actual localizing movements began.

A second striking feature of the results peculiar to this particular series is the fact that of the six subjects, three showed no continued improvement over their first deviations, while the other three made exceedingly rapid progress and soon overcame their small initial remainders. In no other series have so large a per cent of the subjects failed to readjust. The conclusion is suggested that there may be much more individual variation in the extent to which this sort of tactual-kinaesthetic factor is effective, than is the case with sight and touch.

Such a conclusion finds support from the consideration of particular cases. Subject T. K., for instance, readjusted very rapidly, attaining almost 100 per cent recovery at the fourth sitting. He then forged on ahead beyond or to the left of the actual position of the finger, showing an average overcorrection of 1.7 cm. before he settled down again to an approximately correct localization. The curves of the other two who readjusted exhibit merely a slight fluctuation about the true position after recovery has taken place.

It is the results of T. H. B. which most strikingly indicate how helpless an individual may be under unusual conditions when

left to depend upon kinaesthesis alone. Having made no readjustment during nine sittings, at the 10th T. H. B. was permitted to reach out to what he thought was the actual position of his finger, making a conscious correction. He felt sure that he could do this accurately, even while wearing the glasses. His first confident move was to localize buzzer 1 (position 53) at 34, or 9 cm. *farther away* than he had previously been localizing it! During 20 repeated trials he was unable to find his left finger, missing it on the average by a distance of 16.7 cm. to the right! Astonished, he came back the next day determined to localize it accurately this time, but only to repeat the performance of the preceding sitting during 12 more trials. It was only when directed by the experimenter to reach out on the *other* side of the finger, that T. H. B. did touch it by accident. After this, he was able to localize it with a fair degree of accuracy.

A comparison of the average results for the three subjects in this series who did readjust, with those of other series, reveals of course a striking superiority in both quickness and amount of readjustment. The curves for series E in Fig. X are higher at every point than those of any other curves. This holds true even for the end of the 10 day period, for on the average an excess of readjustment occurred. While the 10 day remainders for series A-1, B-1, C, and D are respectively 12.5, 10.8, 1.0 and .4 cm., that for series E is + .49 cm., representing a positive extra readjustment. This tendency to overcorrect was soon checked by all of the subjects who showed its influence. The overcorrection,

TABLE VIII

Tactual-Kinaesthetic Clues from Left Arm

Subjects	No. of Sittings	Visual Acc. 53	66	79	92	Av.L.D. 1st trial	Av.Rem. 10 days	Total Per Cent Readj.
T. K.	10	55.6	66.7	80.7	93.6	9.4	+1.7	118
W. M. S.	10	53.8	66.4	79.6	92.2	8.0	.76	91
M. M.	10	52.0	65.3	78.9	91.6	10.0	+.47	104.2
Average	9					9.1	.49	104.6
N. McL.	9	53.8	65.8	79.2	92.0	11.0	9.7	12
R.	10	52.9	66.2	79.0	92.3	15.1	13.0	13
F. H. B.	11	54.5	66.9	80.1	92.9	11.1	9.6	13.6
Average						12.4	10.8	12.9

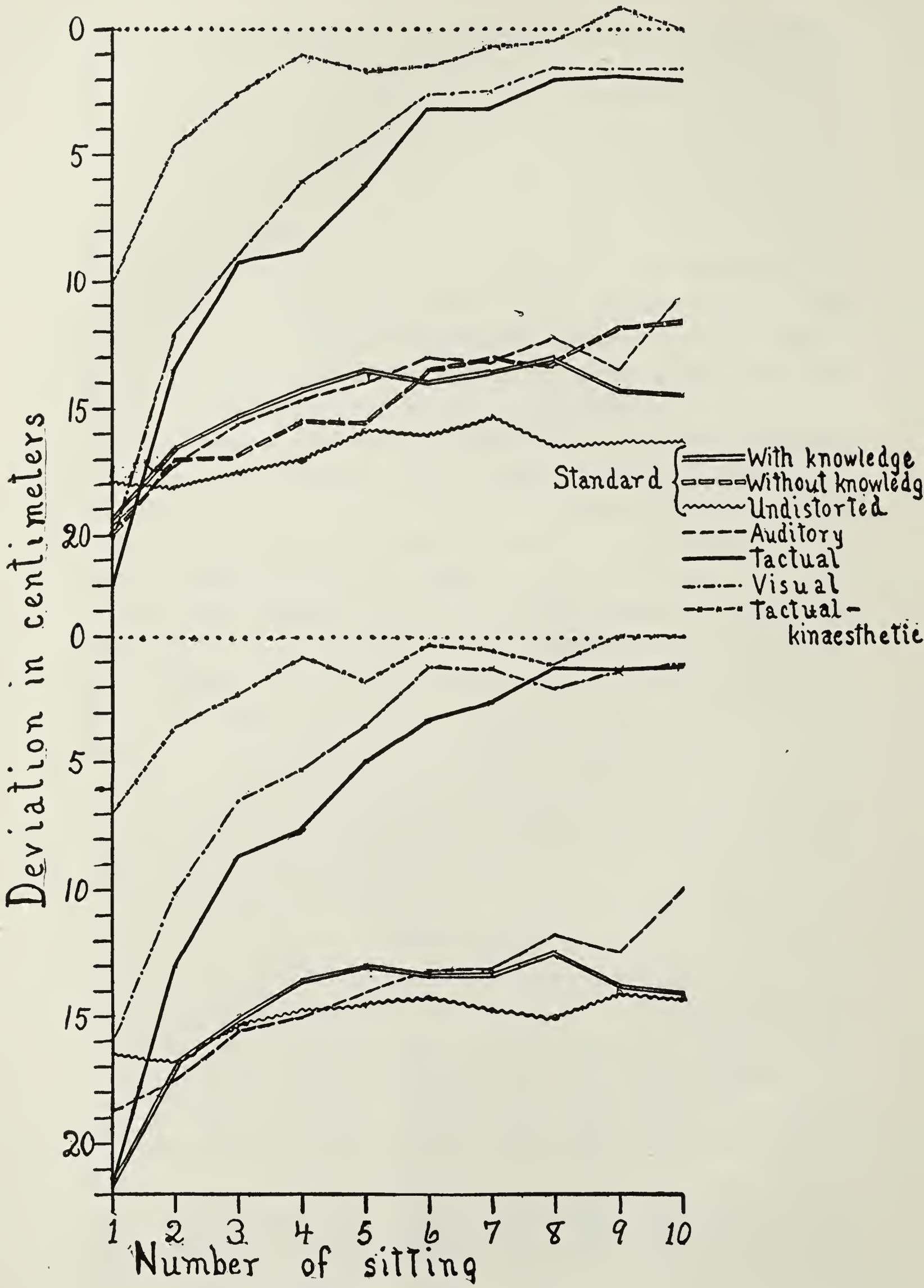

FIG. X. Group Curves.

then, indicates apparently nothing more than an unusually strong impulse toward readjustment.

In considering this striking superiority of the tactual-kinaesthetic factor it must be held in mind that we have after the first sittings another factor lending its weight to the already strong influence of the tactual-kinaesthetic clues from the left arm. This comes from the fact that as soon as the left finger is accidentally touched by the right arm, we have the operation of the direct contact factor the influence of which was seen to be so great in series C. It is no wonder, then, that after actual contact, readjustment is completed almost immediately.

TABLE IX

Summary of Results for All Series

No. of Series	Factor or Condition	No. of Subjects	Av. No. Sittings	Initial L.D.	Rem. 10 da.	Rem. Total	Percent Readj. 10 da.	Percent Readj. Total	Mean Dev. 10 da.
				cm.	cm.	cm.			cm.
A-1-a	Standard with Knowledge	7		19.1	12.5	8.7	35.5	56.0	8.0
A-1-b	Without Knowledge	4		17.7	10.6	9.1	38.8	(47)	10.0
A-1	(a & b)	11	22	18.6	11.8	8.8	36.0	53.0	8.8
B-1	Sound of Buzzer	6		18.3	10.8	7.7	41.5	(73)	10.5
B-2	Sound of Bell	6		19.6	8.0	2.8	64.0	87.5	16.5
B	(1 & 2)	12	26	19.0	9.4	5.3	52.7	80.0	15.5
C-2	Active Touch	5	10	21.8	1.02		94.4		3.9
C-1	Passive Touch								
D	Sight	7	10	17.6	.4		97.0		4.3
E	Tactual-Kinaesthetic	3	10	9.1	.5		104.6		9.0

IV

RETENTION OF THE NEW CO-ORDINATION

The question as to how long the new spatial coördination will be retained, while not strictly pertinent to our main problem of determining the relative influence of the various constituent fac-

tors, has nevertheless some bearing on the problem, since it concerns the stability of the new habit.

We made no effort systematically to investigate the amount of retention in these experiments, or its relation to time of acquisition or the sensory factors concerned. But some weeks after the conclusion of the experimental series we gave one sitting each to such subjects as were still available—seven in all.

The trials were given in the same manner as in the original sittings. The average of the five trials for each position was taken, and the amount of readjustment shown was calculated. This was compared with the previous highest amount of readjustment to show the per cent of retention of the habit.

The results are given in Table X. Some individual cases of retention are striking. The per cent retained by K. E. L., after an interval of 37 weeks, was 77. That of D. S., after 24 weeks, was 90. The most striking case of all, however, is that of H. L. K. After an interval of two years and three months she was given first the test for visual accuracy, without the glasses. In this test her error to the left of her previous normal standard of visual accuracy was 3 cm., with an average deviation of only .9 cm. On taking the 20 trials while wearing the prismatic glasses H. L. K. showed a retention of 47 per cent of the progress made two years before. Considering the fact that H. L. K. had originally only 12 sittings, this amount of retention is striking.

The results for all of the subjects who took the retention test point, then, to a high degree of stability and persistence in the new spatial coördination.

TABLE X

Retention

Subject	No. of Sittings	Series	Approx. No. of Weeks' Interval	Original Readj.	Later Per Cent Readj.	Per cent Retention
D. S.	15	A-1-b	24	57	51	90
T. K.	10	E	24	118	105	89
M. L.	6	D	30	97	78	30
T. L. W.	18	C	24	78	100	78
K. E. L.	31	B	37	82	63	77
H. L. K.	12	A-1-a	116	53	25	47
E. B.	7	D	30	97	86	88

V

DEGREE OF SPECIFICITY OF THE NEW CO-ORDINATION

Does the new spatial habit acquired by the subjects in this experiment carry over to a noticeable extent into normal situations? This question has a general importance theoretically in its bearing upon the whole Kantian and modern controversy concerning the generality of spatial experience. It also has an interest for the narrower purposes of the experimental investigator in the field of space perception. Heretofore the attack on this question has been in general theoretical and to an unfortunate extent controversial. If it should seem possible to throw light on the problem by some such simple experimental procedure as we have employed, then there would be promise of advance in future experimental investigation of the problem.

It proved extremely difficult in this investigation to devise methods that would secure a reliable check on this matter. As soon as we freed the subjects from the rigid conditions imposed at the apparatus in order to observe their behavior in normal situations, we found operating many obscure factors the nature of which it was impossible accurately to evaluate. We believe however that certain tests we used do throw some light on the problem, and give promise that in the future genuinely reliable factual evidence can be secured.

Now if the particular spatial habit we are investigating really does function in general situations, we should find the following conditions to hold:

1. Subjects wearing the glasses at the apparatus should not find the new co-ordination seriously interfered with should any change in the general [illegible]y situation be made.

2. On the removal of the glasses the continued functioning of the new habit should manifest itself in a disturbance of the old or established manner of reaction. This should hold not only at the apparatus table but for attempts to localize objects in ordinary situations.

3. Practiced subjects wearing the glasses should localize ordinary objects with smaller error than unpracticed subjects.

4. Practiced subjects wearing glasses should be able to walk about a building with more ease and efficiency than unpracticed subjects.

These four general criteria we applied in our investigation. In the first place in order to find out whether a change in the general sensory situation interfered with the new coördination, we adopted the following procedure. For three of the groups at the conclusion of the trials with distorted vision, the chair in which the subject sat was shifted 18 cm. to the right, and localizations were obtained as before with the subject reacting from the new position. Now if the new habit was formed merely on the basis of a definite position, with definite tactual and kinaesthetic stimuli, it might be expected that it would be seriously disturbed or even lost were a new position assumed. The shift in position of the chair, however, made no significant difference in the reactions for any of the 20 subjects who took this test. For five subjects in the standard series, ten in the sound series, and five in the sight series, the average difference between the last five trials for the shifted position is only .3 cm. This small difference is positive, or in the direction in which improvement would be expected. There is, moreover, a negligible amount of individual variation, the difference being very small in every case. Hence the readjustment is general in the sense of not being limited to any particular part of the apparatus.

To answer the second question two different procedures were adopted. First the glasses were removed from the subject immediately at the close of the last sitting with distorted vision. Then, still seated at the apparatus he was required to localize the buzzers *as they appeared to him visually,* in the same manner as before, but without the glasses, and of course without seeing his finger.

If the readjustment had been a function merely of the particular conditions of the practice series, with glasses worn, these localizations with normal vision would have been objectively correct, i. e., the subject would have localized the buzzers with

approximately the same degree of accuracy as in the trials for normal visual accuracy given at the beginning of his sittings.

All of the 23 subjects tested in this way, however, made a large error to the *left* of their standard for normal accuracy. For five subjects in series B, six in series C, nine in series D, and three in series E, to whom the test was given, the average error to the left was 9.3 cm. This means that the subjects, having grown accustomed while wearing the glasses to localizing the buzzers by reaching out some distance to the left of *where they looked to be,* now retained the habit when the glasses were removed, and reached out confidently to the left of where the objects objectively *were*. If the new habit had functioned in full strength without the prisms, then the average error to the left would have been 14.8 cm., the average amount of improvement shown during the sittings by these 23 subjects. That it was in fact 9.3 cm. (or 62 per cent of the original amount) indicates a striking degree of transfer of the new formed habit to the normal situation, considering the strength of the customary or old association between object seen and reaching movement, which on the removal of the glasses would be expected to exert a strong influence.

The other procedure adopted for determining the existence of an after effect from the wearing of the glasses was carried out away from the apparatus. The subject, still wearing the glasses, was seated at an ordinary study table and directed to reach out and touch with the index finger certain objects which lay on the table—an eraser, an ink bottle, and a thimble. This each subject was able to do accurately, after a few trials to overcome the small error to the right that he still made. Now the subject was asked to keep on reaching out, touching the objects every few seconds, and not stopping when the glasses were removed. When he had started localizing the objects in this manner, the experimenter quietly removed the glasses. For two of the four subjects given this test the after effect was striking. These two, T. L. W. and K. E. L., continuing to reach out in the same way, missed the objects each time by from two to four cm. to the *left,* although they could plainly see their hands going in the

wrong direction. They were surprised and amused at the result. Both reported a queer "pull" to the left and a feeling of effort or strain as if something were holding them back. Thus in spite of the existence of a sharp conflict between the established system of localization and the newly acquired space habit, the latter continued to exert an influence in this everyday situation. Moreover it required a number of trials for both subjects before they could again reach out and touch the objects accurately.

For the two subjects whose normal reactions were not thus influenced, it seems that the sight of the arm and hand in reaching out may have supplied an overwhelmingly powerful stimulus to unconscious correction to the right while the movement was still under way. Even for the subjects who did feel the after effects the error was so small that it would have led to no difficulty in making practical adjustments unless movements of great accuracy were required; and it is quite possible that the effect was with them only transitory. None of the other subjects after the removal of the glasses reported any interference with normal reactions.

Even if the after-effect is slight and perhaps transitory, however, this test is significant in showing definitely that even such a rapidly acquired and simple spatial coördination as this may function effectively enough to interfere with the longstanding habits of reaction. It is unfortunate that the test was devised too late to give to a larger number of subjects. Together with the test at the apparatus however it furnishes clear evidence that the new habit does exert an influence on normal reactions.

Our third criterion, that subjects who had learned to localize the buzzers more or less correctly while wearing the glasses, should be able with the glasses on, if the habit is general and not specific, to localize ordinary objects with either no error or a smaller error than unpracticed subjects, we subjected to test in two ways. First, we had the subject sit at a study table, and, wearing the prismatic glasses, localize objects placed in definite positions in front of him. Second, we had him walk about the room, pick up objects, walk down a long hall and the like, while we carefully observed his behavior.

For the test at the study table we first tried the following

plan. Five objects,—two ink bottles of different size and shape, an eraser, a small box, and a thimble were placed in definite positions on the table, about 20 cm. apart, and from 25 to 40 cm. from the edge. The subject, wearing the glasses, was seated in front of these objects, with his right arm resting on the table parallel to the front edge. He was instructed to reach out at a natural rate of movement and localize the object *as it appeared to him* with his index finger. The experimenter first named the object, and then at the signal "go" the subject reached out, letting his finger rest where it happened to fall until the experimenter had noted in centimeters the amount of error to the right.

The first tests given with this method showed it to be unreliable. The errors were found to be very small and to decrease markedly after the first trial. But far from indicating a transfer effect this only showed that a powerful factor was operating within the time of the test to decrease the amount of error. This factor seemed evidently to be the sight of the arm, which, after the reaching movement was started, would serve as a strong stimulus to correction to the left. Such a conclusion is in line with the statement of a number of the subjects that although they tried honestly to locate the object as it looked to them, they felt a strong "muscular urge" or "pull" to the left against which they had to resist.

With the idea of at least partially obviating such a tendency to correct and thus of getting a measure of the transfer effect, we hit on the plan of having later subjects reach out *very quickly* to the object, believing that there would thus be much less likelihood of the direction of the movement being changed, once started.

Twenty-seven subjects took the test in this form. The numerical results for all individuals are given in Table XI, p. 81. Although two trials were given for each object only the first is given here. In practically all cases the error was much less, approaching zero, on the second trials. Since there was considerable variation in the position of the subject's chair, his distance from the objects, and the order in which they were named, these results are a very rough measure only of the relative amount of error, and it

would be useless to attempt to deal with group averages and comparisons. The individual results, however, are worth studying.

The objective errors due to the prismatic distortion would have been from 20 to 35 cm., according to the position of the objects. But the errors shown in the table are very much less. The smallness of the errors however can not be due primarily to transfer. This is shown in the first place by the fact that the error markedly decreased after the very first trial. For example: for the first object the error of E. B. in the Tactual Series is 20 cm. and for the second object only 7 cm. For F. in the Visual Series the error for the first is 15 cm. and for the second 2 cm. Subject F.'s remark, "I feel an irresistible pull to the left," indicates the nature of the stimulus which influenced other subjects though in lesser degree, to decrease their errors. Evidently the sight of the arm in reaching and the visual perception of the discrepancy between object and localizing movement, initiated kinaesthetic impulses so strongly in conflict with the reaction originally released as to modify its direction.

A second type of evidence that the smallness of the errors is not the direct result of transfer of the new space habit, lies in the consideration that there is no apparent relation between the amount of error in this test and either length of practice or the amount of readjustment attained. The results of M. W. and M. K. in the Visual Series illustrate this point. M. W., after 63 sittings and complete readjustment, still made an extremely large error; while M. K., who took only 10 sittings and showed very little readjustment, made much smaller errors, and these were quickly eliminated.

The main indication, however, that the transfer effect is not great in this test comes from comparison with the results of an unpracticed group. Nine students who had heard of the glasses but had never worn them before, were given the same test at the study table but this time with four objects instead of five. From the results in Table XII, p. 81, we might at first glance conclude that the regularly larger errors are due to lack of practice with the glasses. But in the first place it is seen that there is the same decrease with successive trials as in the practiced group, and the

TABLE XI

Initial Errors to Right in Centimeters for Specificity Test at Study Table. No Screen, Quick Reaction.

Group	Subject	Objects					Number of Sittings	Average Total Rem.
		1	2	3	4	5		
Standard	O. B. B.	9	10	11	14		22	9.5
	W. A. O.	4	4		5		27	3.5
Auditory	C. W. L.	16	12	12	0	4	45	4.2
	F. B.	6	3	0	0	10	25	1.3
	K. E. L.	9	13	9	7	4	31	3.8
	C. S.	0	0	0	0	0	25	.2
	M. M.	14	10	8	10	2	40	3.6
Visual	M. C.	3	4	2	7	3	10	4.5
	F. D.	7	9	4	2	6	11	.5
	D. B.	6	6	4	3	3	13	2.0
	M. B.	2	2	4	2	3	10	.2
	F.	15	2	2	1	0	10	.96
	M. K.	11	12	7	2	18	10	18.0
	T. L. W.	15	7	12	7	3	18	1.4
	R. D.	8	3	6	5	7	10	10.2
Tactual	J. L. B.	13	15	16	12	19	17	1.4
	P. J. R.	7	4	3	4	9	10	2.3
	H. G.	11	3	2	3	4	10	.2
	A. D. U.	9	6	4	4	2	12	.2
	E. B.	5	20	4	7		7	.5
	P. I.	3	7	0	4	12	7	1.1
	J. H. B.	2	13	7	1	6	5	.45
	M. P.	4	4	8	0	0	6	.4
Tactual-Kinaesthetic	T. K.	11	12	11	9		10	1.7
	W. S.	10	12	13	7	16	10	.76
	M. My.	12	4	4	13	14	10	.47

TABLE XII

Errors to Right in Specificity Test. No Screen. Quick Reaction. Unpracticed Group.

Subject	Objects			
	1	2	3	4
E	14.0	21.0	5.0	12.0
W	12.0	4.0	2.0	6.0
F	9.0	3.0	2.0	9.0
Fl	15.0	12.5	0.0	8.0
R	12.0	13.0	7.5	11.5
Fr	14.0	16.0	0.0	3.0
H	12.0		3.0	11.0
B	12.0	11.0	2.0	4.0
S	18.0	12.0	4.5	16.0
Average	13.3	10.4	2.9	8.9

same individual variation. In the second place it is true that the experimenter with the unpracticed group took more pains to impress on the subjects the point that they were not to correct to the left. In the third place the errors, even though relatively larger than for the practiced group, are still on the average half or less than half what the objective uncorrected error would have been.

It follows then that our second plan for securing a fair measure of the transfer effect was unsuccessful, and that so far there is no clear evidence that the new habit functions in every-day situations.

A third plan was tried after the regular series had been concluded. The experience of the writer, M. W., pointed to a possible source of error in the fact that a more rapid rate of movement was prescribed for the test than the natural rate employed during the original building-up of the habit at the apparatus. M. W. did not complete her readjustment and take the tests with objects at the study table until after practically all the other subjects had finished. She found then that when she reached out very quickly to localize the objects, she missed them on the average by as much as 17 cm. But when later she tried reaching out at a *natural* rate of movement she missed them, if at all, by only one or two centimeters! The same results were obtained at several later times. This suggested that the other subjects may have been making more than their natural amount of error, since the directions had been explicit to move very quickly. Such a conclusion is in line with the work of Woodworth on movement. He found that a simple movement automatically performed at a natural rate, was made with much less accuracy when the rate was greatly increased.[1]

It seemed likely, then, that our test of the generality of the new coördination had not been a fair one. An attempt was made to check the accuracy of this conclusion by giving the test in a modified form to four students who had formerly served as subjects and had attained varying per cents of readjustment.

[1] Woodsworth, R. S. "Le Mouvement." Paris, 1903. Ch. XV.

First, wearing the glasses, they practiced making localizations at the apparatus, with sight of the finger, until a test given by the experimenter showed that they could localize the buzzers with a constant error of less than one centimeter to the right. (Since readjustment takes place very rapidly in the sight series, and since the four subjects reached out as often and for as long a practice period as they pleased, it only required from one to four sittings to make complete readjustment again.) The subjects were then given the tests with objects at the study table, this time with two changes. First, they reached out at a natural and not a forced rate of movement. Second, the movement of the hand and arm in reaching was carefully screened by a cardboard cover so that the finger was seen only when the reaching movement was concluded. The last precaution was observed to aid in obviating the incentive to correction afforded by the sight of the arm.

The results as given in Table XIII are from too few subjects to justify definite conclusions. While it is worthy of note that none of the errors are significantly larger than in the preceding test, there is still no evidence on the basis of results for these four subjects that the additional precautions taken (of using the

TABLE XIII

SPECIFICITY TEST

At Study Table—with Cardboard Screen—Natural Rate of Movement.

Subject	Per cent Readj. Original	Per Cent Readj. With Practice	Approximate Errors in Cm. to R. of Objects 1	2	3	4
T. L. W.	100	100	7		6	5
K. E. L.	10	100	5	3	3	2
H. L. K.	40	100	7	0	9	6
E. S. R.	53	100	12	14	13	11
Average			7.7	5.61	7.8	6.0

Group	No. Subjects	Average Error in Cm. for Objects 1	2	3	4
With Screen	9	18.0	23.0	10.6	17.4
Without Screen	9	13.0	10.4	2.9	8.9

screen and adopting a natural rate of movement) affected the results.[2]

TABLE XIV

Specificity Test at Study Table, with Cardboard Screen. Natural Rate of Movement. Unpracticed Subjects.

Subject	Error to Right in Cm. 1	2	3	4
G. C.	20	24		15
L. M.	26	25	16	22
G. K.	18	20	13	14
R. W.	17	16	7	13
W. B.	19	24	7	21
H. C.	28	28	16	21
N. G.	26	22	16	16
E. B.	22	25	12	17
R. L.	7	21	9	18
Average	18.1	22.8	10.6	17.4

Comparison of the results of this modified test with practiced subjects with results of the same test given to nine unpracticed subjects does seem, however, to reveal significant differences. Table XIV gives the individual results.

On the face of it these results would indicate that the larger amount of error—over twice as great as for the practiced subjects—must be correlated with lack of practice, and hence that there is evidence of decided transfer of the space habit to the study table situation. Again, however, the experimenter here took special care to instruct the unpracticed subjects not to correct to the left, but to locate the objects as they appeared to be—a care not exercised in the same degree with the practiced subjects. This source of error alone may possibly account for the difference in the results. We may say, however, that this situation does furnish some evidence, though of doubtful value, for transfer.

It is not surprising that if we were unable to get conclusive evidence for transfer to ordinary situations from the test with objects

[2] That the use of the screen does help to obviate the tendency to correct is, however, shown in a comparison of the results of larger groups of *unpracticed* subjects, who were later given short tests at the study table. The results are as follows:

Group	No. Subjects	Average Error in Cm. for Objects: 1	2	3	4
With Screen	9	18.0	23.0	10.6	17.4
Without Screen	9	13.0	10.4	2.9	8.9

at the study table, we were similarly unable to observe any clear differences in the behavior of practiced and unpracticed subjects while walking about the room. Both practiced and unpracticed subjects managed to walk about and perform ordinary acts with no serious mishaps. In general for both there was a constant tendency to walk to the right and to reach out to the right of the actual position of objects. The greater the distance and the quicker the movement the greater were the errors. Errors in reaching were also much greater when the movement of the hand was not seen. There was for most subjects swaying and unsteadiness in walking, as long as visual guidance was employed, and general hesitation and confusion in movement. Some subjects made much greater errors to the right in reaching for objects than others; but among the ten unpracticed subjects thus observed, the errors varied in extent practically as much as with practiced subjects.

We might conclude that these observations indicate that there is no transfer to everyday situations. Two considerations, however, show that this conclusion would not be justified. In the first place, unpracticed subjects in these everyday situations are under the influence of very powerful sensory incentives to immediate readjustment. If the mere visual perception of amount of error, as in Series D, is a strong incentive, how very much stronger will be the perception of the discrepancy in the total sensory situation! In the second place even were an actual transfer effect present in the case of practiced subjects, it might be obscured by the operation of other factors. For instance, subjects who had readjusted to the spatial situation, as far as direction was concerned, might still be unable to judge distance correctly. The writer found that many of her errors were made in estimating depth and distance, not direction. For instance, it was very difficult to walk downstairs with visual guidance, not because of any temptation to go to the right, but because the steps looked curved and much lower than they actually were, and there was consequently an inappropriate muscular reaction.

Much of the uncertainty of the practiced subjects may have been due, then, to this difficulty in adjustment to changed dis-

tance relations. Other disturbing factors are the limiting of the field of vision by the frame of the glasses, and the fact that the stationary prisms in front of the moving eyes produced dizziness and, with a few subjects, even nausea.

But while our observation of the general behavior of the subjects in ordinary situations offers no clear negative evidence on the question of the general nature of the new space habit, neither does it offer positive evidence.

While in general it seems that transfer to ordinary situations is slight, if existent at all, there is evidence that there are individual differences in the matter. Some subjects consistently made large errors both at the study table and in walking about the room, while others made negligible errors, or none.

Subject C. S. of the Auditory Series is one for whom the new habit seemed to carry over effectively into ordinary situations. She had learned to localize the buzzers without error at the apparatus in 25 sittings. At the study table she reached out with perfect ease for the objects, making absolutely no error even on the first trial. (See Table XI). Considering the limitation of the visual field by the glasses, she made her way about the room with ease, making no mistakes in direction.

Subjects M. B. of the Visual Series, with ten sittings, may also possibly have retained the effects of practice in normal situations. Her errors at the study table were all small (the first being only 4 cm.) and soon disappeared. M. B. found it "perfectly easy to get around the room and see objects." She walked about confidently, picking up objects here and there and reaching out for door knobs and the like without any observable sign of a tendency to go to the right. She reported that things looked natural to her, and that when she reached out to touch things they "seemed in the right position." She said she felt no muscular strain or "pull" away from objects, as most other subjects did.

No subjects in the practiced group were able to adapt themselves so well to ordinary situations as M. B. and C. S. It must be remembered, however, that these two are exceptions in the practiced group, and that others in that group constantly made large errors in direction. In the case of subject E. B. of the Visual Series, for instance, the new habit seemed to hold only

for very specific situations. E. B. had made a readjustment of 97 per cent in seven sittings. After taking the trials for visual accuracy without glasses at the end of the series, she found that when she began localizing with glasses again she made just as large an error to the right as at the beginning! It took 30 trials to bring her up again to her newly acquired standard of correct localization. Again when seated at the study table she missed the first object by 20 cm. but the error quickly decreased in the following trials. In walking about the room with the glasses on she again experienced great difficulty, making large errors constantly unless she went very slowly and calculatingly.

The writer, when she had finally attained complete readjustment after 63 sittings, found great difficulty in walking about the room and down the hall. Unless she disregarded the looks of things and trusted to the established kinaesthetic-tactual habits, she made constant errors to the right when distances of several feet were invloved, as for instance, in walking rapidly to a door knob from the middle of the room. In walking down a long hall she bumped into the right wall every few feet unless she used her right arm as guide. But within more definitely prescribed areas her errors were much smaller. In fact as long as she used a natural rate of movement and looked carefully at the objects she was reaching for, she made either very small errors or none at all. Her very large errors at the study table (15 to 28 cm.) were evidently due to the disturbing effect of an unnatural rate of speed, for when she reached out at a natural rate, even with the movement of her arm screened, she localized the objects almost perfectly even on the first trial. In general whenever she moved about the room naturally, without thinking particularly what she was doing, she found herself able to localize correctly almost any object she wished to touch. She found on trial that she was able to serve herself at the table without difficulty, reach for the salt, put sugar into her coffee, etc., without any false movements. It was only when she moved very quickly, or approached objects quickly from some distance, that serious errors to the right were made.

The conclusion is that in M. W's case the new habit probably

functioned to a considerable extent in normal situations as long as the general kinaesthetic setting was the same as prevailed while the new coördination was forming. The very small errors which did appear were easily and unconsciously overcome in the making of practical adjustments. But when large distances were involved the error, being proportionately greater, would inevitably be sufficiently large to interfere with practical accuracy, even though there was a transfer effect. The general confusion, hesitation, and slight dizziness can be accounted for on the basis of other disturbing factors previously mentioned.

None of the unpracticed subjects were able, judging from appearances, to localize objects with the ease and naturalness of M. W., and certainly not with the ease of C. S. and M. B. Moreover the unpracticed subjects were unanimous in reporting a decided "pull" or muscular conflict while some of the practiced subjects, among them the three just named, felt no such muscular strain. For the writer, accurate reaching movements were made with absolutely no feeling of strain or effort.

We may conclude that for some subjects at least there is evidence that the newly acquired habit of judging direction in visual space does function in normal situations. It proved impossible to isolate the various factors involved sufficiently well at the study table to test out accurately the transfer effect there, yet there is some evidence for it even from those tests. More accurate methods are needed and could no doubt be devised.

The consideration of individual cases, however, both at the study table and in more general situations, indicates plainly first that there may be a pronounced carrying over of the habit in the case of some subjects; second that a slight transfer effect probably exists for some subjects but is obscured by other disturbing factors; and third that there are probably marked individual differences in the extent to which the new habit is generalized.

The general conclusion from all the experiments on specificity is that the new space habit is by no means a merely limited and specific mode of functioning, but that it may affect reactions in more general conditions than those prevailing in the original

experiment. The wider significance of this fact is contained in the statement that the systems of retinal and general kinaesthetic habits involved in the new spatial coördination apparently function to a greater or less degree in general situations. This conclusion must be put forward very tentatively, owing to the unsatisfactory nature of the general experimental control.

It is clear, moreover, that the amount of transfer is for most subjects not very marked. In view of the fact that the glasses were worn but a short time, we would not expect the system of habits acquired during that time to have much influence on the old system of retinal-motor habits which has been functioning since infancy. The surprising thing is that there is any interference at all. Considering the conditions of the experiment we have here a remarkably stable and well organized habit system, which functions automatically while the glasses are worn and even carries over to some extent into the established reaction system.

Incidentally it is interesting to note that the new reaction pattern did not disintegrate between trials, but carried over in full strength from one day's sitting to the next, in spite of the conflicting modes of adjustment employed meantime. Thus we have two distinct sets of complex retinal-motor habits, alternating at short or long intervals according to the stimulating situation (whether the glasses are worn or not). This fact is suggestive in connection with the phenomena of alternating personality, in which the same principles operate though on a vastly more complex scale.

VI

RELATION OF READJUSTMENT TO DEFINITE LOCALIZING ACTIVITY

A complete study of the process of the formation of a new spatial coördination would involve an examination of its relation to overt motor activity. Is readjustment conditioned by active efforts to make some definite motor adjustments to the new

situation, or may it occur when the subject takes a merely passive attitude?

It was our original plan systematically to investigate this aspect of the problem. This we could do by giving only one trial per sitting for one group of subjects, and comparing the results with those of groups having, let us say, 20, 40, and 80 trials per sitting. It would be desirable also to devise a method of response by verbal identification instead of active reaching. We did not have time to carry out this plan.

It was thought, however, that some light might be thrown on the problem (especially in so far as it concerns reasons for readjustment in the standard series) by finding out whether or not any readjustment would occur while the subjects merely sat passively without making any overt response at all. It was not practicable to use the apparatus for this purpose, and so with the four subjects used the procedure was as follows:

The subject, wearing the prismatic glasses, was first given a test at the apparatus, to determine his average linear deviation for each of the four buzzers. He reacted by movement of arm and hand as in preceding series. Three trials were taken for each position.

The subject was then seated at a table in another room. After the glasses were put on he remained there passively for 20 minutes, viewing objects in the room, but making no overt localizing movements *of any kind*. Ten such sittings were given. At the close of the tenth, the subject was again seated at the apparatus, and the amount of deviation determined as before.

The results are given in Table XV. A number showing positive increase is preceded by a plus sign and one showing regression by a minus sign. Three of the four subjects show absolutely no decrease in deviation after the ten "passive" sittings. One made an average increase of two cm., but this increase occurred for only two of the buzzers. On the average, there was even a slight regression from the actual position of the buzzers.

There were too few cases, and too small a number of trials in each case, to justify sweeping conclusions. Moreover had the sittings been taken at the regular apparatus, and had they been continued longer, the results would have been more con-

clusive. They do, however, indicate clearly that under these particular conditions no significant readjustment occurs without definite localizing movements. We may say provisionally, then, that apparently the process of readjustment to the new spatial situation is conditioned by definite and overt adaptive movements on the part of the subjects.

TABLE XV

Difference between Initial and Final Localizations

Subject	53	66	79	92	Av.
C. J. W.	+2.0	—5.0	—3.3	+ .5	—1.5
O. W.	+1.6	—2.2	+1.0	— .8	—1.0
A. O. U.	+ .6	.0	+4.6	+3.3	+2.1
J. S.	— .7	—4.9	—1.4	— .9	—1.5

VII

SUMMARY AND CONCLUSIONS

The outcome and signficance of our experiments may be summarized under twelve main heads as follows:

1. No readjustment to the changed visual situation occurred without definite reaching movements of the hand while the eye was fixed on the visual object. Thus the development of the new coördination seems to be conditioned by definite localizing activity on the part of the subject. The process of forming the new habit seems to consist largely in the association of visual and tactual stimuli with kinaesthetic stimuli involved in the localizing movements. This observation is entirely in accord with Stratton's experience. "It was repeatedly noticed in the course of the experiment", he says, "that the total experience was much more harmonious during active movements of my body than when I inactively looked upon the scene." And again "The scene itself became more my own by acting upon it, and this action reacted to bring the representation of my body into harmonious relation to the scene."

2. There was a progressive readjustment in the standard

series, although there were apparently no sensory stimuli indicating the actual position of the object. This seems to represent an unconscious adaptation of the reaching movements to the new kinaesthetic stimuli from the eye muscles. In other words, pare of the readjustment that occurred was not a reorganization of response with respect to the actual position of the object, but represented an adaptation to particular sensory conditions induced by the wearing of the prisms. It is reasonable to suppose that the readjustment in the standard series was due to the tendency of the subject mechanically to react with the hand in response to the old habitual concept of "front" associated with head position, rather than to the new definition of "front" involved in the altered position of the eyes in the head. If so, this would indicate that when there is even a slight disturbance of the customary relationship between ocular-motor habits and general bodily habits, the individual mechanically and unconsciously varies his reactions in such a way as to bring the latter into harmony with the established type of reaction. In any case it seems that slight changes in the delicate muscular mechanism regulating the eye may profoundly influence the overt reactions of an individual although he may be entirely unaware of the effect on his behavior of the new kinaesthetic stimuli.

Experimental verification and further investigation of this hypothesis are needed. While the existence of this hypothetical ocular-motor stimulus to progressive readjustment has presumably interfered with the quantitative accuracy of our measurements of the relative efficacy of various sensory factors, yet its existence as a conditioning factor, if well established, would still be profoundly significant. For it would indicate anew, in a striking way, the extreme intricacy and delicacy of the complex system of retinal and general habits which, developing and functioning automatically, constitutes our spatial experience.

3. Subjects in the auditory series in which the sound offered a sensory clue to the actual position of the subject, showed on the average no stronger tendency to react closer to that actual position than those in the standard series. There may be individual cases in which sound was effective but on the whole the conclusion

is justified that under the conditions of our experiment sound is not an effective factor in the formation of the new spatial coördination.

4. When contact was used as a practical check on the efficacy of the localizing movement, a new habit of localization, objectively correct, was very rapidly built up. Such a new coördination is formed on the basis of mere chance contact, but there was no regular and systematic learning until the subject was allowed each time to check the accuracy of his reaching movement by definite exploratory contact with the buzzer. The combined factors of kinaesthesis and contact then proved to be very important in the formation of the new coördination.

5. Visual perception of the amount of error served as the most powerful single sensory factor in the development of the new habit. The evidence is conclusive that in our experiment vision was at least as efficacious as the combined tactual and kinaesthetic factors involved in active touch; and there is good evidence that it is definitely a more efficacious factor. In this regard our experiments strongly support a tentative hazard of Stratton's for which he was, on the basis of his experiment, unable to adduce direct factual evidence. In discussing the question as to whether or not visual direction is dependent upon tactual direction, he says "If there is any dependence either way (which I doubt) the evidence seems to favor the primacy of sight." In his own experiment there are a number of indications that this is the case. An example is the fact of stubborn persistence of the "old" localization of parts of the body *not visible*. Another is the reference to the old system of the legs in motion while walking, *if not in the visual field at the time*. Evidently the direct visual perception of the amount of error made under the new or disturbed conditions was for Stratton as for our subjects an exceedingly powerful sensory stimulus to new adaptive reactions. The conclusion is strongly suggested that if it had been possible to isolate the contact factor, studying its effect apart from the kinaesthetic stimuli involved in the exploratory movements the "primacy of sight" would have been far more strikingly demonstrated.

6. By far the most rapid acquisition of the new coördination occurred in the tactual-kinaesthetic series, in which the sensory clues to the tactual position of the object (left finger in this case) consisted in a whole system of tactual and kinaesthetic impulses coming from the left arm. We would expect such a wealth of sensory impulses, intimately concerned as they are in so many everyday habitual coördinations, to serve as exceptionally strong stimuli to readjustment for the same reason that we expect the human infant to learn more easily and quickly to localize parts of his own body than external objects. Strange to say, however, of the six subjects in this group only three reacted rapidly to this effective complex of stimuli. The other three were absolutely uninfluenced by the stimuli from their own bodies. One was at the conclusion of the series in absolute ignorance of even the approximate position of his unseen localizing hand! Thus there are evidently striking individual differences in the extent to which the development of a new spatial habit may be conditioned by stimuli from bodily position.

7. The new spatial coördination formed under the conditions of our experiment was retained for long periods of time, functioning at a considerable per cent of its effectiveness even after a lapse of from one to two years. This is in line with experiments on the retention of other bodily habits, and is one among other indications that the learning process involved in the acquisition of the new habit is of a sensory-motor character.

8. The new coördination is not merely specific for the particular conditions of its formation, but maintains itself when the experimental conditions are changed. It even in some cases shows a transitory influence on reactions to ordinary objects after the glasses are removed. This shows that with our type of experiment it is possible to study quantitatively the process of discarding an acquired spatial habit-system. Stratton found that after the removal of his glasses his localization of ordinary objects was interfered with, there being now a tendency to make the opposite type of error, but he was unable of course to gather quantitative data on the extent of the interference.

9. The new space habit seems clearly, for some individuals,

to function in general everyday situations. This conclusion is of practical significance in indicating that this type of experiment may be useful in investigating the question of degree of generalization in the acquisition of spatial habits.

10. There are striking individual differences in the extent to which various sensory factors contribute to the formation of the new spatial coördination, in the time required for its development, and in its strength and stability once acquired. For most subjects tactual and kinaesthetic factors are very efficacious, but for some they have apparently no influence at all. Vision is effective for all our subjects, but in different degrees. Hearing seems possibly to be efficacious for some, but is unquestionably not an influential factor for others. For some the new coördination is easily disturbed, for others not.

Such considerations as these point emphatically to the need for extensive quantitative investigation of the whole subject of the acquisition of spatial reactions. It seems quite likely that much of the disagreement concerning pathological cases as well as normal reactions in the genesis of spatial experience for individuals may be due to a failure to consider the possibility of wide individual differences in the matter.

11. There is no evidence from these experiments that the new coördination was formed on any other than a purely sensory-motor basis. At first it was thought that knowledge of the nature of the error might be a factor making for readjustment, but the control experiments without knowledge disproved this hypothesis. The later experiments abundantly bore out this conclusion. While such factors as interest, conscious shifting of attention, emotional attitude and the like undoubtedly influenced the type and rate of progress of the readjustment or learning at various points, most of it occurred on a purely mechanical or automatic level, while the subject was entirely unaware of the nature of his reactions. Even in the visual and tactual series the subject was aware only of the end results of his reactions, which were in no case, according to the reports of the subjects, under ideational guidance or control.

12. Perhaps the most significant result of this investigation

is the demonstration that it is possible to secure accurate and extensive quantitative data on the problem of the factors in the development of space perception, through the use of relatively simple experimental procedure. We are keenly aware of many defects both in apparatus and in procedure. In the course of the experimenting, however, we have seen ways of obviating these defects which promise much in the way of future investigation of the problem.

BF21 .P96 v.32
Memory defects in the organic
Princeton Theological Seminary-Speer Library
1 1012 00008 5383